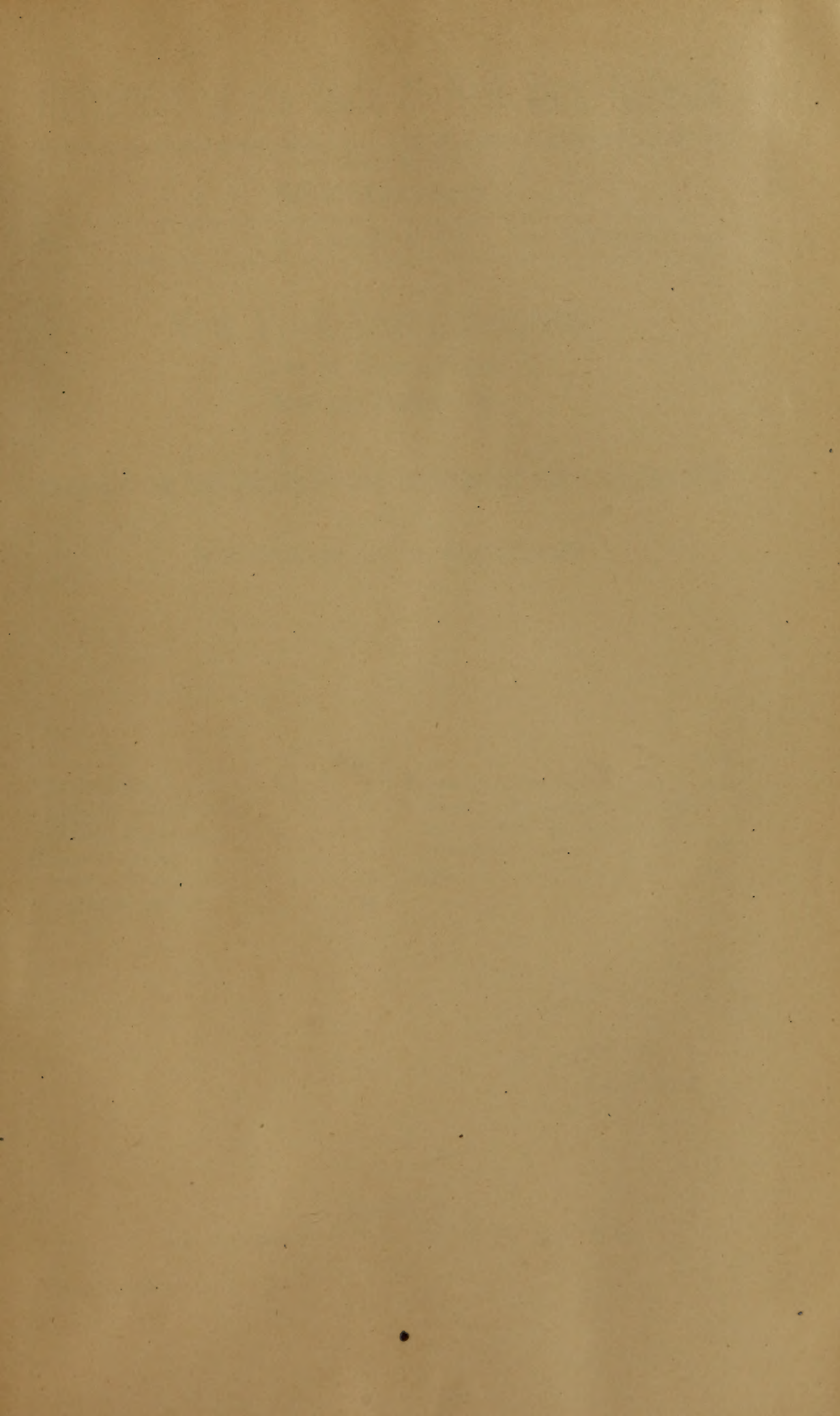


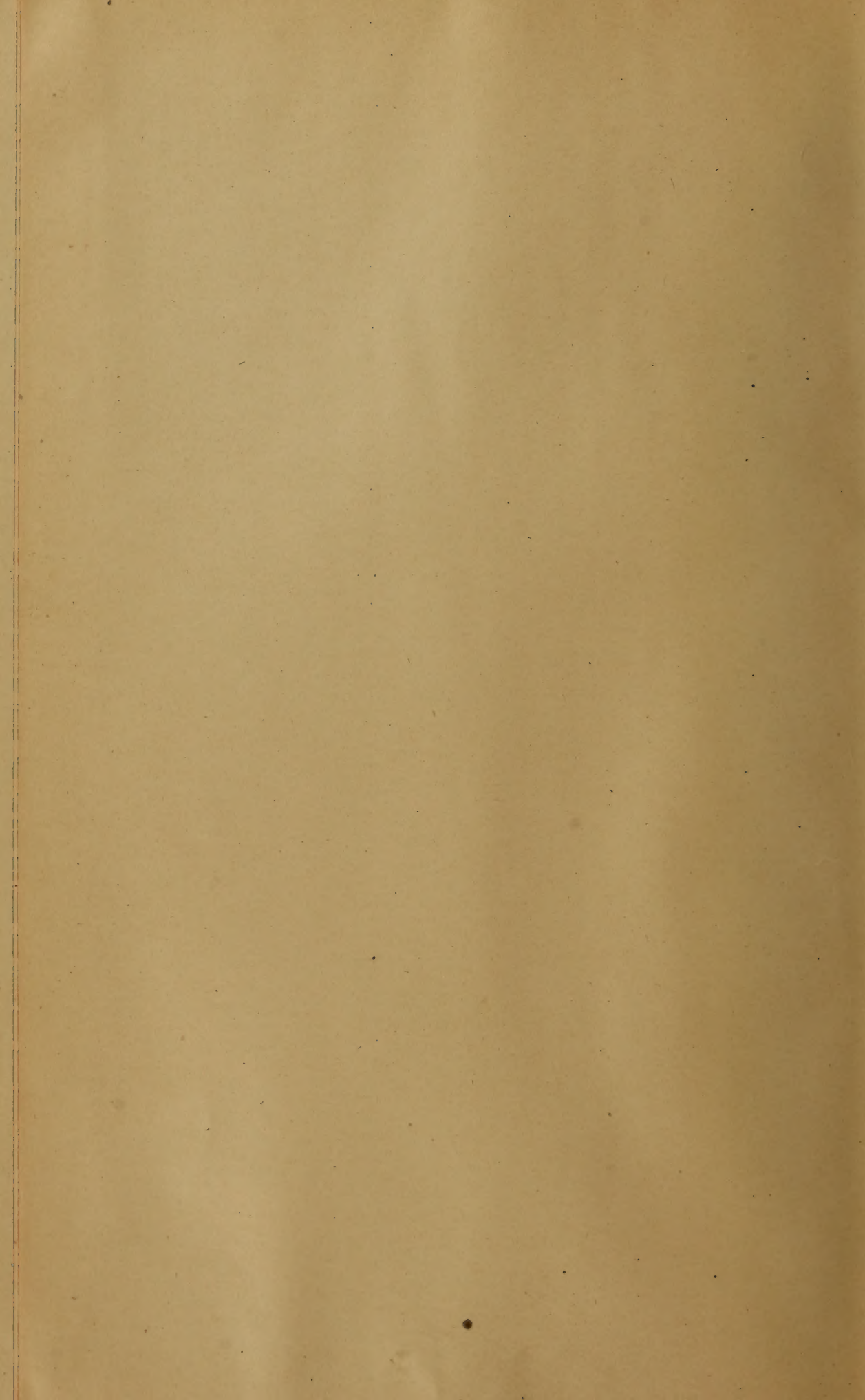
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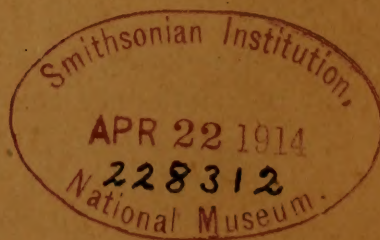
Museum Bulletin 169

GEOLOGY OF SARATOGA SPRINGS AND VICINITY

BY

H. P. CUSHING AND R. RUEDEMANN

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THE UNIVERSITY OF THE STATE OF NEW YORK

1914

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New York State Education Department

Science Division, March 28, 1913

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Commissioner of Education

SIR: I have the honor to communicate herewith, and to recommend for publication as a bulletin of the State Museum, a manuscript entitled the *Geology of Saratoga Springs and Vicinity*, with the necessary illustrative matter accompanying.

This report has been prepared at my request by Doctors Cushing and Ruedemann, in response to a public demand for information in regard to the geological conditions existing about and causing the Saratoga mineral springs.

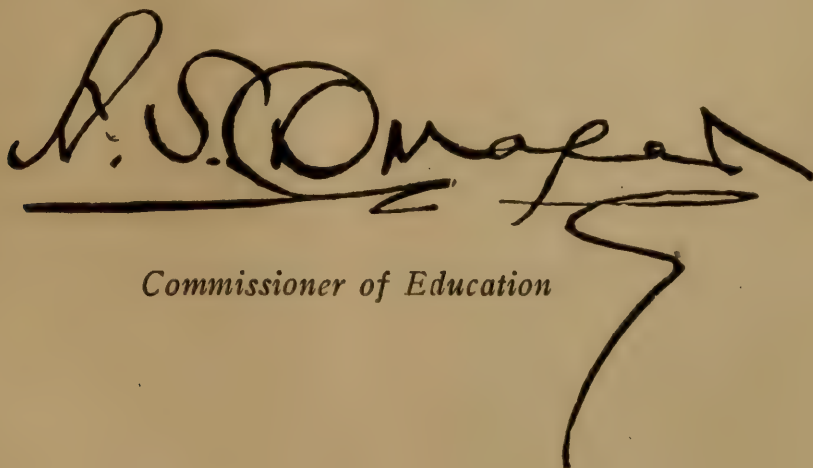
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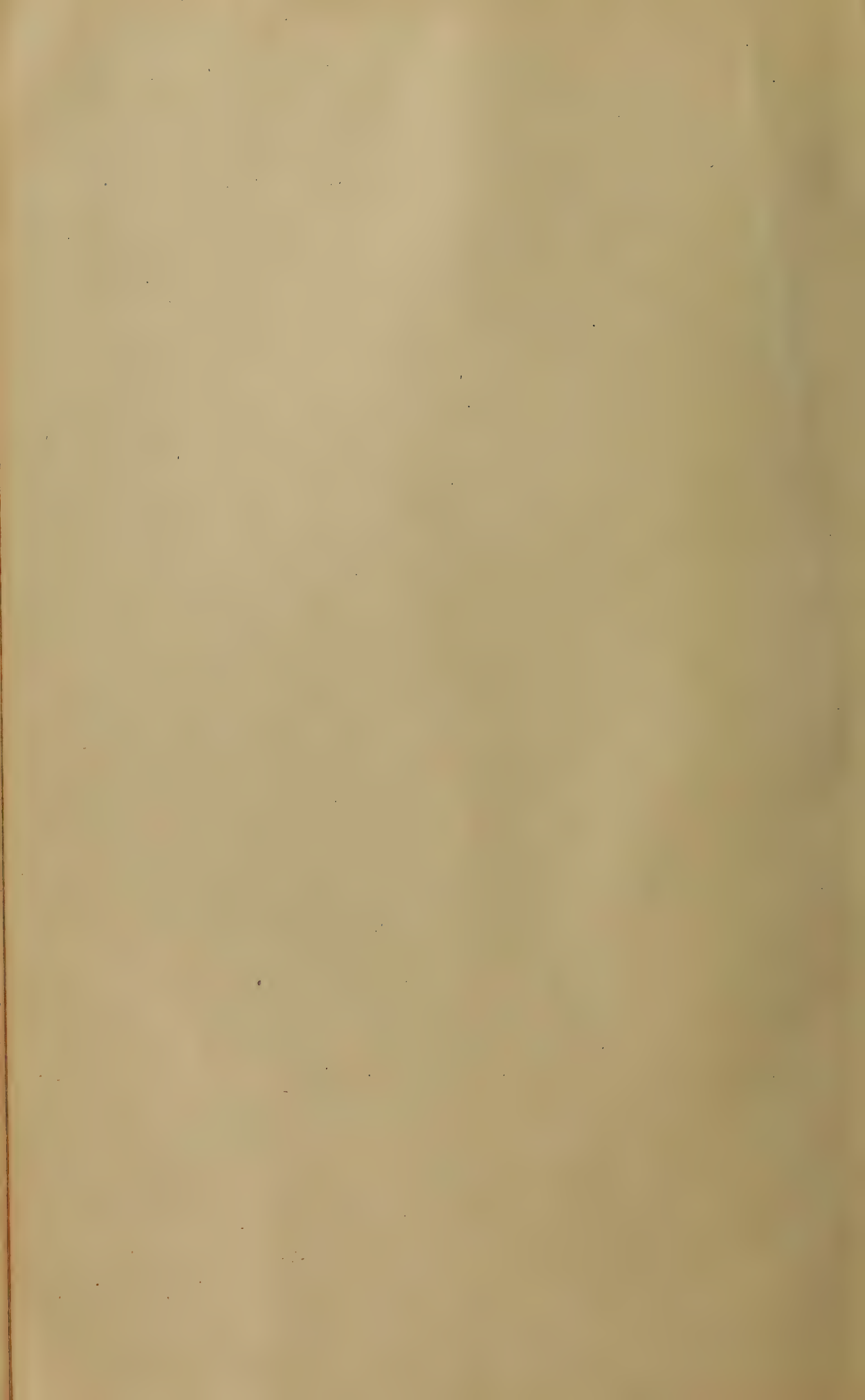
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STATE OF NEW YORK
EDUCATION DEPARTMENT
COMMISSIONER'S ROOM

Approved for publication this 3d day of April 1913

A large, stylized handwritten signature in black ink, appearing to read 'A. S. Conner'. The signature is written over a horizontal line and has a long, sweeping flourish extending downwards and to the right.

Commissioner of Education



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Museum Bulletin 169

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BY

H. P. CUSHING AND R. RUEDEMANN

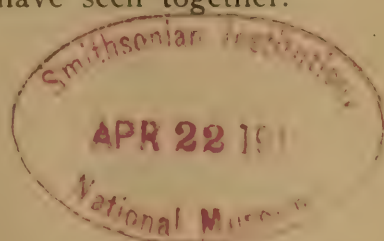
INTRODUCTION

BY H. P. CUSHING

The presence of a group of well-known springs whose waters are of a somewhat unusual type, has long given prominence to the region about Saratoga. A variety of causes has recently increased this prominence and rendered it desirable that the geology of the region should undergo more thorough investigation than it had ever received, in the hope that light might be shed upon the question of the origin of the waters and the duration of the supply.

It was the original plan to include in this report the geology of the Broadalbin quadrangle, next west of Saratoga, which was assigned to Dr W. J. Miller, but later developments led to the abandonment of this plan and Doctor Miller's report has been published separately.¹ That work was done in close association with our own, and in addition Doctor Miller also mapped some 30 square miles in the extreme northwest corner of the Saratoga quadrangle. This service is emphatically acknowledged since the country concerned is unsettled and difficult of access, and the aid was rendered at a time when the writer was unable to engage in field work as laborious as that which this district entailed. With this exception, Doctor Ruedemann and myself are responsible for the mapping. Much of the territory we have seen together.

¹ N. Y. State Mus. Bul. 153.



The classifying and mapping of the shales is wholly Doctor Ruedemann's; and the whole Schuylerville quadrangle also with the trifling exception of the extreme northwest corner.

During the progress of the work an invitation was extended to Prof. J. F. Kemp to collaborate in the study of the spring waters. Circumstances later developed which rendered it advisable to publish the report which he drew up as a separate paper and in advance of the main report.¹ The aid rendered is gratefully acknowledged.

During the progress of the field work several geologists have spent some time with us on the ground, and given most helpful suggestion and counsel. Days spent with Messrs Ulrich, Kemp, Smyth, Van Ingen and Miller are in no slight degree responsible for whatever of merit may lie in this report.

Over much of the Saratoga sheet glacial drift is so widespread and thick as to render hopeless the attempt to accurately map the geology beneath, which is peculiarly unfortunate because the geology is complicated and difficult. This has been the chief, and a very great, drawback to the successful prosecution of the work.

LOCATION AND CHARACTER

BY H. P. CUSHING

These two quadrangles, the Saratoga and Schuylerville, lie in extreme eastern New York, about midway of the State from north to south. The territory included lies between latitude 43° and $43^{\circ} 15'$ N, and longitude $73^{\circ} 30'$ and 74° W, hence extending over $\frac{1}{4}^{\circ}$ of latitude and $\frac{1}{2}^{\circ}$ of longitude. It falls just short of containing 450 square miles.

The district includes parts of several topographic and geologic provinces. Bits of the southeast margin of the Adirondack highland, included by Powell in the province he called the New England plateaus, are seen. This highland is separated from the high Appalachian plateau of southern New York by the Mohawk valley lowland, a valley eaten out by stream erosion along the belt of weak shales which are the surface rocks through most of it. To this lowland belong the shales of the southern part of the Saratoga quadrangle.

The Adirondack highland is separated from the main mass of the New England plateaus by the low grounds of the Champlain-

¹ N. Y. State Mus. Bul. 159.

Hudson trough. This is not a mere valley of erosion but a true trough, having been repeatedly depressed as compared with the districts east and west of it. Erosion has had its part in the development of the valley, but as a secondary instead of a primary factor. In the mapped district this lowland is seen merging into the Mohawk lowland. Across the Hudson, along the east margin of the Schuylerville sheet, rises a range of hills, the outlying western rampart of the New England plateaus.

Turning from topography to geology we find the old crystalline rocks of the Adirondacks coming into the district from the north. These are margined by the flat-lying sandstones, limestones and shales of early Paleozoic age which were deposited in the Champlain basin, even in that early time a sinking trough. These in turn are adjoined on the east by the series of much disturbed shales of the Hudson valley, a quite different series of rocks from those of the Champlain basin. They were deposited, also in early Paleozoic times, in a wholly separate and more easterly trough than the Champlain basin, and have been brought to their present location by being thrust over to the west by the action of great compressive forces. As rocks they are not indigenous to the region, but exotic. Still farther east come the limestones and impure shaly rocks of the Bald Mountain ridge, also overthrust into the district from the east. These rocks are so different from those of the Champlain basin that we are of necessity constrained to describe and discuss them in separate chapters.

In two minor features the geology of the region is unique. One of the Paleozoic formations of the Champlain basin, the fossiliferous, Upper Cambrian limestone which was first described by Walcott, occurs as a surface formation in New York only in the immediate vicinity of Saratoga.¹ Just north of Schuylerville there outcrops a knob of extrusive igneous rock, first recognized and described by Woodworth, which is unlike any other known igneous rock of the State, and which has been made to play a part in one theory of the origin of the spring waters.²

¹ U. S. Geol. Surv., Bul. 30, p. 21-22.

² N. Y. State Geol. 21st Ann. Rep't, p. 117-129, 1901.

GENERAL TOPOGRAPHY

BY H. P. CUSHING

ADIRONDACK HIGHLAND

The surface rocks of the Adirondack highland are ancient crystalline rocks of Precambrian age. The district is one with an inherent tendency to be elevated and to move upward rather than downward, or at least not to participate in the sagging tendency of adjacent territory during times of oscillations in the crust of the earth. Such a region is spoken of as a positive one, to distinguish it from districts of the negative type, whose tendency is to depress. At certain times in the past the margins of the highland have been sufficiently depressed to pass beneath sea level and become covered by marine deposits. But the central area of the plateau seems never to have been depressed in this manner, or at least not since very early in Precambrian time; since then it has had a continuous existence as a land area. From time to time it has been uplifted and its surface has experienced much erosion. Between the periodic uplifts long ages of stability have intervened. During these stable intervals the surface has been the scene of incessant erosion, chiefly by stream and rain action. The ultimate effect of such prolonged erosion on a stable land area is to wear it down to a comparatively even surface with low altitude. Such an erosion plain is called a peneplain. If a peneplained district be again uplifted, stream activity is renewed and the whole erosion process again set in motion.

The Adirondack highland has certainly been peneplained twice during its history, and quite likely more than twice. The earlier of the two peneplains was completed in Precambrian time, and it was upon this peneplained surface that the early Paleozoic deposits of northern New York were laid down, about the margins of the Adirondacks. These covered and preserved this old erosion surface and portions of it are reappearing at the present-day surface, as the Paleozoic cover is stripped away from it by modern erosion.¹ Its comparative evenness is surprising, when the great variation of the rocks composing it in resistance to erosion is considered.

In considerable part the present Precambrian surfaces of the Saratoga quadrangle represent fragments of this old peneplain, though somewhat modified by comparatively modern erosion. This Precambrian peneplain was developed over a wide area and is

¹ N. Y. State Mus. Bul. 145, p. 54-60.

recognizable over a large part of Canada and in the Upper Lake region as well as in the Adirondacks.

A much later peneplain, of probable late Mesozoic date, was also developed in the region, and again it was merely the local development of a peneplain of wide extent in eastern North America. Prior to its development, deformation of the region had upwarped the older peneplain into the form of a gentle dome, and at the same time downwarped the margins into shallow troughs in which early Paleozoic sandstones, limestones and shales had been deposited. The Mesozoic peneplain truncated the domed summit of the older peneplain; but on the margins of the region the two surfaces intersect and the older passes beneath the younger. The Paleozoic rocks lie upon the surface of the older, and the younger cuts across them (figure 1). An attempt to illustrate the manner in which, by erosional stripping back of the Paleozoic cover, portions of the old peneplain surface are exposed to view at the margins of the Adirondacks, is seen in figure 2.

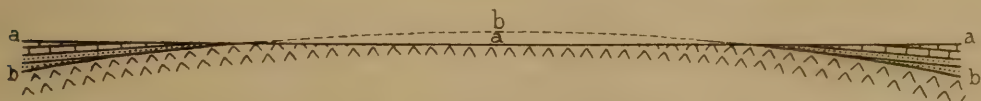


Fig. 1 Domed surface of Precambrian peneplain, *b b b*, with marginal Paleozoic deposits, both truncated by late Mesozoic peneplain, *a a a*. Vertical scale much exaggerated.



Fig. 2 Diagram in illustration of the manner of reappearance of the old Precambrian peneplain at the present surface; *a b* = late Mesozoic peneplain; *c d* = tipped surface of old peneplain, in part covered by Paleozoic rocks; from *c* to *c*, however, the Paleozoics have been recently removed by erosion, reexposing the old peneplain surface; modern erosion has cut valleys in both peneplain surfaces, but the ridge summits are remnants of these surfaces.

Since the development of the Mesozoic peneplain the highland has been again uplifted, the uplift being greatest along the eastern border. This has given the peneplain surfaces a tilt to the west. Since this uplift the present valleys of the region have been cut below the surface of the Mesozoic peneplain and, on belts of weak rocks, have become broadly developed. The entire surface of the Saratoga and Schuylerville quadrangles is below the level of the peneplain, with the possible exception of the hill summits in

the vicinity of Black lake. The uplift was accompanied by dislocations of the peneplain surface, owing to movements along the great fault planes of the region, which broke up the uniform surface into a mosaic of flat-topped blocks at varying levels. Because of this dislocation and the modifying effects of subsequent erosion, the recognition of the peneplain surface in the eastern Adirondacks is a matter of considerable difficulty. The western Adirondacks were uplifted without dislocation, and there the peneplain is easily recognized.

The Adirondack highland is a moderately rugged region with much bare rock and comparatively little good soil, and is forest-covered throughout. In winter it is tenanted by the lumberman, in summer by the tourist and the river-driver. The population is scanty and scattered. The region is strangely poor in mineral wealth. But the forest and the water power are of great value; and no less so are the invigorating climate and the charm and beauty of wood and water.

THE MOHAWK LOWLAND

Since the uplift of the Mesozoic peneplain, the weaker rocks of the region have been deeply eroded. Along belts of weak rock, valleys have been carved, the valley bottoms representing the beginning of development of a new and lower peneplain. Not far south of the Adirondacks runs a great, east-west belt of weak shales, and into them the valley of the Mohawk has been carved as a great belt of lowland between the Adirondack plateau on the north and the plateau of southern New York. Great faults cross the valley bringing up masses of more resistant rock, as at Little Falls, St Johnsville, Sprakers, Tribes Hill and Hoffmans Ferry, and in these the lower valley narrows and its walls steepen. Otherwise the valley is broad and wide.

East of Hoffmans it becomes especially wide, on approach to the region of deformed rocks of eastern New York, in which the strike of the rocks approximates a north-south direction. The belt of shale broadens northward, curving around to merge with the Hudson valley lowland.

HUDSON VALLEY LOWLAND

From Fort Edward to Poughkeepsie the Hudson occupies a broad, often very broad, valley eroded in a belt of soft shales, quite similar to the Mohawk valley. The shales are also of quite

similar character. But unlike the shale belt of the Mohawk, these shales are greatly deformed. They have been compressed, folded and faulted, and show steep dips nearly everywhere, instead of lying flat. The boundary between the two shale belts is fairly abrupt, and is readily traced across the Saratoga district. The shales of the Saratoga quadrangle are the undisturbed shales of the Mohawk belt, while the greater part of those of the Schuylerville quadrangle are the tipped shales of the Hudson valley belt. The greater part of the Schuylerville quadrangle is included in the Hudson lowland.

There are occasional harder bands in these tipped shales, bands of hard sandstone or grit and chert, whose lines of outcrop form low ridges on the otherwise level valley floor. Glacial deposits also diversify it somewhat, as they do along the Mohawk. Close to the river they have been washed away, but back from it they rise in prominent benches and widely cover the valley floor so that rock outcrops are very exceptional.

Two hilly tracts of land rise from this plain, one east of Saratoga lake, culminating between Ketchums Corners and Quaker Springs and attaining the 600 feet level; the other in the northeast corner of the Schuylerville sheet, north of the bend in the Moses kill. A landmark in the broad plain north of Fish creek is Kendrick's hill rising 200 feet above the plain.

The hilly region at the eastern edge of the Schuylerville sheet is the western margin of a plateau of somewhat higher level. This plateau is but little higher than the Hudson river plain; its base is about 400 feet above sea in the west and it rises gradually to about 600 feet across the adjoining Cambridge sheet to the eastern edge of that sheet, where another somewhat abrupt rise takes place to a higher plateau. We will call this lower plateau, which is about 10 miles wide, the Greenwich plateau. It can be traced on the east side of the Hudson across the Hoosic into Rensselaer county and south, where it lies in front of the Rensselaer plateau and has been fully described by Dale.¹ This plateau is characterized by its extremely irregular surface, as shown on the eastern edge of the Schuylerville sheet. It is covered with a great number of more or less oval hillocks, mostly but a few hundred feet high, but in many cases rising 500 feet, and in some even a thousand feet above the plain. It gradually approaches the Hudson river until at Troy

¹ Dale, T. Nelson. *Geology of the Hudson Valley between the Hoosic and the Kinderhook*. U. S. Geol. Surv. Bul. 242. 1904.

it forms the bluffs of the east bank of the river and thence merges into the Hudson river plain.

DRAINAGE

The two quadrangles drain entirely into the Hudson, the Schuylerville directly, the larger part of the Saratoga indirectly. The chief portion of the latter drains through Kayaderosseras creek into Saratoga lake, and thence by Fish creek into the Hudson, while the extreme northwest reaches the river by the still more indirect route of the Sacandaga.

Across the Schuylerville quadrangle flows the Hudson through the structural valley of the lowland just described. In structure this valley is the direct continuation southward of the Champlain-Wood creek valley. The Hudson enters this valley at Fort Edward, north of which there is a low divide of Pleistocene materials between the Hudson drainage and Wood creek. Between Corinth and Fort Edward the present position of the Hudson was never before occupied by a large stream, but is apparently a composite of portions of the narrow valleys of small preglacial streams. A small portion of this stretch of the river's course is seen on the two quadrangles, the remainder lying within the Glens Falls sheet. In this part of its course it shows frequent and abrupt changes in direction, abrupt variations in width, and frequent falls and rapids. At Corinth the water level is 520 feet, at Fort Edward 140 feet, and the distance is less than 12 miles in an air line, though much more following the river. This is a fall of over 30 feet to the mile.

At Corinth the river is in another structural valley of good size, which in preglacial times must have been occupied by a considerable stream. It has followed this valley for many miles through the mountains. Structurally this valley continues to the south across the Saratoga quadrangle and is now occupied by Kayaderosseras and Sturdevant creeks. It is heavily filled with Pleistocene deposits, especially at the north, and it was this depth of drift filling which turned the Hudson aside into its modern course through Glens Falls. The deeper channel of the valley is indicated on the areal map, and the valley continues on to the south past Ballston and through Ballston lake to the Mohawk at Schenectady.

In this vicinity, then, the present Hudson is occupying portions of two ancient, structural valleys, while its course from Corinth to

Fort Edward is its postglacial route of passage from the one to the other.

Aside from the river, the two principal streams of the district are Batten kill, coming into the river from the east, and the Kayaderosseras creek — Fish creek drainage from the west. This latter basin covers most of the Saratoga quadrangle and about one-third of the Schuylerville as well. Only the lower portion of Batten kill lies within the map limits, some 7 miles long following the stream, but only a little over 4 miles in an air line. In this short distance it drops over 200 feet. The larger part of this drop is made at Middle Falls and at the fall 1 mile below Middle Falls, unnamed on the map. This part of the stream's course is wholly modern and postglacial.

All the upper portion of Kayaderosseras creek lies in the deeply drift-filled, structural valley running south from Corinth. Heavy drift across the valley east of Middlegrove turns the stream aside and its course between Middlegrove and West Milton is modern and to the west of the old valley, with the chief drop at Rock City Falls. At West Milton it reenters and crosses the old valley, then turns south through Ballston in a modern course, with frequent rapids and falls. Below Ballston it flows through a shallow valley wholly in drift to Saratoga lake. Below the lake it is a sluggish stream with little fall in preexisting valleys until the big bend just below Victory Mills is reached. The final mile and a half of the stream is again in a modern channel, with a drop of nearly 100 feet.

On these three streams, because of their steep gradient, there are numerous water-power sites, all of which are occupied and in vigorous use. Few districts show as thorough utilization of power possibilities.

GLACIAL DEPOSITS

On the higher grounds of the district there is no great thickness of glacial deposit, and the topography and bedrock geology are well shown. But at the lower levels, and chiefly in the two great valleys, there is abundant and often thick drift, constituting an important element in the topography. This drift is in part glacially deposited and in part a water deposit.

MORAINES

No terminal moraine of any particular prominence lies within the map limits, though there is a considerable morainic belt running across the northern portion of the Saratoga quadrangle. But there

is a tremendous lateral moraine terrace banked up against the mountain front along the west side of the Kayaderosseras valley and a smaller but similar one along the Mt McGregor front. These would seem to have been deposited along the sides of the ice lobes which occupied these valleys during the retreat of the last ice from the region. They are overspread with sand in varying amount, deposited from streams supplied by the melting ice, which flowed along the margins of the ice lobes between the ice and the valley wall.

DRUMLINS

These are oval-shaped hills of drift, chiefly till, supposedly formed underneath a glacier near its end. There is a group of ten or a dozen such hills in the Kayaderosseras valley, grouped in a rude triangle whose apex is the large drumlin just south of Kings, on the Adirondack branch of the Delaware & Hudson Railroad, and whose base extends across southern Greenfield township into northwest Milton. Shaped by the ice, the longer axes of such hills are supposed to trend with the direction of ice movement. In this group the trend varies from north-south to south 20° west. They show prominently on the topographic map.

A group of hills of similar appearance, east of Saratoga lake, Schuylerville quadrangle, are rock hills and not drumlins at all. Harder bands in the tipped shales, either chert or sandstone, are responsible for these hills.

TERRACES

There are several broad terraces of sand and gravel within the mapped limits, chiefly the delta deposits of streams formed during the ice retreat from the region. Batten kill built a great delta in the higher water levels of the time, forming a great terrace east of the Hudson, banked up against the base of the hills, from Bald mountain southward, the larger part of it being south of the present position of the stream.

Running southwest from Gansevoort through Wilton is a tremendous sand terrace, which continues on into confluence with the similar terrace to the east and south of Saratoga Springs. The summit levels of this terrace are quite like those of the Batten kill delta. Southwest of Saratoga Springs, in Milton township, is another great sand terrace, at a somewhat higher level than the other two. In the valley south of Corinth, hemmed in between the higher grounds on each side, is a smaller sand delta, at a much higher level.

The deposits of these terraces were laid down in close proximity to the ice sheet, occasionally covering stranded blocks of ice. When this melted away, depressions were left which became occupied by ponds. Three such ponds lie in the sands south of Corinth; and Moreau pond, northwest of Gansevoort, and Lonely lake near Saratoga lake, are larger examples. Saratoga lake itself lies in an old drainage valley, and in a portion of it which was less deeply filled with drift than the remainder.

GENERAL GEOLOGY

BY H. P. CUSHING

The surface rocks of the Saratoga and Schuylerville quadrangles belong apparently to two separate geologic provinces. The rocks of the Saratoga and the western portion of the Schuylerville quadrangle are those of the Adirondack plateau and the lower Mohawk trough; those of the remainder of the Schuylerville quadrangle are deposits of more eastern troughs. The Adirondack plateau rocks are of Precambrian age and comprise both sedimentary and igneous rocks. Those of the Mohawk trough are of early Paleozoic age, Cambrian and Ordovician, and contain no igneous rocks in the Saratoga region. Those of the more easterly troughs are also of early Paleozoic age, Cambrian and Ordovician. But the formational units are quite different from those of the Mohawk trough, and the two are also very unlike structurally.

Except for the cover of comparatively recent deposits of Pleistocene age there are no rocks in the region younger than the Ordovician, with one trifling exception, and that an igneous rock. A mile north of Schuylerville, on the west bank of the Hudson, is a small knob of extrusive rock of peculiar character, which is certainly younger than the Ordovician and in all probability very much younger.

STRUCTURE

Since their formation the rocks of the Adirondack region and the Mohawk trough have been considerably deformed. The Precambrian rocks of the Adirondacks were enormously deformed in Precambrian time and folded in a complex manner, while the sediments were all cut to pieces by great intrusions of igneous rock from beneath.

Besides this early deformation the rocks of the eastern Adirondacks have undergone subsequent deformation, in common with

the Paleozoic rocks of the Champlain valley. This has chiefly expressed itself in the formation of a great number of normal faults, both large and small. The Paleozoic rocks of the trough are but little folded and usually but slightly tilted, but they are cut into great slices by a series of normal faults which trend about north-northeast, and which are themselves broken by occasional cross faults. Most of these faults downthrow to the east, but at the same time the upthrow side is given a tilt to the west, forming a valley when combined with the upthrow side of the next fault to the west. Occasional faults throw to the west, with the result that a depressed structural valley called a graben is formed.

The drop from the level of the Adirondack highland to the low grounds of the Mohawk trough is produced by a series of these great faults, all throwing to the east.

Passing from the Mohawk rocks to those of the more easterly troughs, one finds a quite different kind of structures. In the first place the rocks are much more folded. The chief structures here are also faults, but instead of being nearly vertical and normal, they are quite flat and are overthrusts, along which great masses of rock have been pushed westward for miles. Unlike the Mohawk rocks, they now lie far from the area where they were originally deposited and form a jumble of overthrust masses. Their structure is exceedingly, often hopelessly, complicated.

DESCRIPTIVE GEOLOGY

BY H. P. CUSHING

The exposed rocks of the two quadrangles are of Precambrian, Cambrian and Ordovician age, together with the unconsolidated deposits of Quaternary age and the small exposure of extrusive rock of unknown age north of Schuylerville.

PRECAMBRIC ROCKS

The Precambrian rocks of the Adirondack region, so far as known, are comprised in an old series of sedimentary rocks, named the Grenville series, which are the oldest known rocks of the district, and in various masses of igneous rocks all of which cut the Grenville rocks intrusively and are therefore younger. The oldest of these igneous rocks is a granite called the Laurentian. Later than this came a series of intrusions, anorthosite, syenite,

granite and gabbro, in the order named. These probably represent a group of closely related intrusions not widely separated in time from one another. Much later came renewed igneous activity with intrusion of diabase (trap), found exclusively as dikes cutting all the other Precambrian rocks.

Representatives of all these rock groups occur in the Saratoga region. The Grenville rocks are abundantly represented; Laurentian granite is probably present, that is to say there is abundance of a granitic rock which we regard as probably Laurentian; the second group of intrusions is represented by abundant syenite and apparently by that alone; and occasional trap dikes of large size belong to the last group.

GRENVILLE SERIES

The Grenville series in the Adirondacks exhibits an enormous thickness of limestones, quartzites and various sorts of schists. On the Saratoga quadrangle the bulk of the Grenville consists of schists, but there is also a considerable amount of quartzite. Limestone is present only as occasional thin bands in the quartzite series. A few miles farther north, however, much more limestone comes in. A considerable belt in which there is much quartzite, interbedded with thin bands of schist and limestone, contrasts so strongly with the remainder of the Grenville that we have mapped it separately. With this exception the intricate admixture of various schists absolutely defies detailed mapping.

In addition, the series is everywhere cut to pieces by a white, granitic rock of somewhat peculiar type, that we have heretofore been regarding as a Grenville sediment. The reasons for regarding it as an igneous rock will shortly appear. We have mapped separately three areas of this rock, but the mapping is vague and highly conventional. The rock is found everywhere throughout the Grenville area, inextricably mingled with the schists. In these three areas it exceeds the schists in quantity and is mapped separately to give conventional expression to our views respecting its nature and relationships. We are provisionally regarding it as Laurentian, that being the term applied to the ancient granitic rocks which, throughout Canada, the Upper Lake region and the Adirondacks, invade and cut to pieces the oldest known clastic deposits. The uncertain feature of this correlation, so far as the Adirondacks is concerned, is that the Laurentian granite, in the Lake Superior region, is older than the Lower Huronian, hence the use of the

term in the east necessitates holding either that the Grenville series is also older than the Lower Huronian, or that the Laurentian granite is younger than about Lake Superior, since the granite is certainly younger than the Grenville.

GRENVILLE SCHISTS

As has been stated, Grenville schists exist in such great variety and with such rapid alternations as to defy detailed mapping and to render detailed description laborious and profitless. The schists are everywhere intricately involved with hard, white, garnetiferous gneisses which, heretofore regarded as sediments, seem to the writer to be plainly igneous rocks. They cut the schists intrusively and develop pegmatites. In the majority of exposures they are merely injected along the foliation planes of the schist, forming injection gneisses and looking extremely like interbanded sediments. The more common of the schists are mica schists, and the prevailing Grenville combination of the quadrangle consists of the interbanded mica schist and white granite.

These mica schists vary from very weak rocks with abundant mica to much firmer ones in which mica is scant. Because of weakness, the former variety is seldom seen in outcrop, but several cuts through such schists expose them well along the Adirondack Railroad a mile north of Saratoga. The firmer varieties outcrop everywhere.

These schists are feldspar-quartz-mica combinations, and nearly everywhere contain in addition pink garnets. The mica is biotite and the bulk of the feldspar is plagioclase, oligoclase to andesine. Quartz forms in general from 10 to 25 per cent of the rock. Foliation is thorough and even.

On the one hand these mica schists grade over into amphibolites, which are heavy black gneisses composed essentially of plagioclase feldspar and hornblende, with usually black mica and pyroxene in addition; on the other hand they grade into hard, light colored feldspar-quartz gneisses, by diminution in the mica present.

The garnets seem to owe their origin to contact action of the white granite upon the schists, as will be later shown. Graphite is a frequent mineral in the schists.

The schists are in chief part metamorphosed shales, as indicated clearly by their composition and structure. They have been entirely recrystallized, injected in complex fashion by granite, and vastly changed in appearance and character. Originally they varied

somewhat, clay shales alternating with sandy shales, and these with calcareous shales. These original variations are still discernible in the schists as bands of varying character, whose chief differences from one another are in the relative proportions of the three common minerals, quartz, feldspar and mica, which compose them.

Grenville amphibolite. There is not a great quantity of amphibolite in the Grenville of the Saratoga quadrangle, and such as there is occurs mingled with the other Grenville rocks in masses of no great size. It occurs in two different ways. On the one hand it forms comparatively thin bands, so interbedded with the other Grenville rocks as to make it highly probable that it represents a band of sediment, a probable original calcareous shale. These bands often appear to grade into the general schists which are interbedded with them. On the other hand it occurs in more or less oval masses which, notwithstanding their small size, seem to cut through the other Grenville rocks, instead of being interbedded, and hence to represent igneous rocks of somewhat later age instead of contemporary sediments. The former are commonly, though not always, heavier, denser and blacker rocks than the latter. Amphibolites of both types occur abundantly in the Adirondacks, but it is by no means always possible definitely to determine to which type a given occurrence belongs, especially when the masses are as small as on this quadrangle.

Grenville quartzite. The chief belt of Grenville rocks other than schists is an east-west belt about a mile in breadth of surface outcrop, which crosses the Saratoga quadrangle through Greenfield township from just west of Kings Station to Mt Pleasant. This is not a belt of solid quartzite, but consists of numerous beds of quartzite, interbanded with various schists and with thin beds of crystalline limestone. The central part of the belt, downfaulted into the Kayaderosseras valley, is covered by younger rocks. West of Mt Pleasant it is cut out by syenite. Though occurring in thin bands elsewhere, the Grenville quartzite and limestone of the quadrangle are practically confined to this belt.

The quartzites present substantially the same varieties as are common elsewhere in the Adirondacks. There are beds of coarsely crystalline, glassy looking quartz rocks, in which quartz constitutes from 70 to 90 per cent of the rock, and the remainder is chiefly feldspar. The finer grained quartzites are usually less quartzose, though with quartz always forming 50 per cent or more of the rock. They are usually quartz-feldspar or quartz-pyroxene rocks. The latter

are less abundant about Saratoga than the former. They are often somewhat micaceous, a brown phlogopite being the usual mica. Pyrite is also a common mineral, and the pyritiferous quartzites, on weathered surface, have the pyrite weathered out and replaced by a brown limonite stain.

Much of the quartzite contains graphite sparingly. There is a thickness of at least 100 feet that contains it in sufficient quantity so that it has been worked for graphite at two different localities on the quadrangle, 1 mile southwest of Kings Station and 2 miles west of Porter Corners. The rock is quite similar at the two places, being granular and considerably altered. It is interbedded with quartzites and quartzose mica schists and is itself a graphitic quartz schist. At the Porter Corners locality the rock is a quartz-feldspar combination, about 50 per cent quartz, 40 per cent feldspar, and the remainder graphite and mica. In the special bed worked there is but little mica and nearly 10 per cent of graphite. Above and below more mica comes in. The feldspar is very badly altered.

At the Kings Station locality the rock is so similar as strongly to suggest the identity of the horizon. On first appearance, the rock seems richer in graphite than at Porter Corners, and may be so; but it certainly contains more mica than that, a disadvantage from the standpoint of successful working. The rock in both places is very similar to that which has been worked for years about Hague; and though it is quite possible that there may be more than one horizon of such graphitic quartzite in the Grenville, it seems more reasonable to assume but one, in default of definite evidence to the contrary.

Grenville limestone. But two beds of limestone were seen in the Grenville of the quadrangle, one noted only at the dam of the Kings Station graphite mill, the other in two localities, about a mile apart along the strike, between 3 and 4 miles west of north of Kings Station. Each is about 10 feet thick, impure, and closely associated with heavy, black amphibolites, which are very common border rocks to the limestones in the Adirondacks and were originally very impure limestones.

The limestone of these two beds is far from pure, the calcite constituting not over 50 per cent of the rock. The most common of the other constituents is quartz, but scapolite, pyroxene, phlogopite, graphite and titanite are also present. Much of the rock is fine grained and of a gray tint, instead of being the usual, coarsely crystalline, white marble of the region.

PRECAMBRIC IGNEOUS ROCKS

General statement. In order of age the Precambrian igneous rocks of the quadrangles are the Laurentian (?) granite, the syenite, and the trap (diabase) dikes. There are in addition very small and occasional masses of amphibolite which are probably original gabbros and younger than the syenite, but they merit only passing notice because of their small bulk and problematic character.

Laurentian (?) granite. A previous statement makes reference to a white, granitic rock, intricately involved with the Grenville schists, which is a common constituent of the Grenville throughout the southern Adirondacks and which we have heretofore regarded as a Grenville rock. Thus Cushing, reporting upon similar rocks from the Little Falls quadrangle, classes them as Grenville.¹ Kemp and Hill describe the similar rock from the "Noses" in the Mohawk valley as a Grenville sediment.² The problem is an involved one since the granite is seldom pure but has everywhere taken in a considerable amount of the adjacent Grenville rocks, giving rise to a mixed rock composed of varying amounts of granite and schist. The recognition of pegmatitic phases of the rock threw the first doubt upon its sedimentary character; afterwards it came to be recognized that the granite itself, as well as its pegmatites, was intrusive as regards the schists. The chemical analysis eventually settled the question.

The granite is a difficult rock to describe because it is nearly everywhere so involved with the schists, or with material from the schists, as to make rock free from such contamination difficult of recognition. The mica is the most obvious of the contributions from the schist, which is certainly much richer in that mineral than the original granite. Hence arises a tendency to infer that those portions of the granite freest from mica are those least contaminated. Such portions show a very white rock composed of white feldspar and quartz and a very little black mica (biotite). In addition are small amounts of apatite, titanite, zircon, and magnetite. Pink garnets are always present but are not regarded as original minerals of the rock. They are most abundant in the schists which have been thoroughly impregnated with granite, and have in most cases resulted from corrosive interaction between the minerals of the two rocks. In other words, most of the garnet is

¹ N. Y. State Mus. Bul. 77, p. 17-19.

² N. Y. State Geol. 19th Ann. Rep't p. 132-135.

a contact mineral. Its occurrence in the pegmatites, however, suggests caution in ascribing it all to such a source.

The granite is chiefly found thoroughly interbanded with the schists, injected into them parallel with their foliation, forming apparent beds of hard, white gneiss which alternate with those of schist. The beds vary in thickness from a few feet to many. It is only in exceptional cases that the granite can be seen to cut across the schist foliation. It is quite otherwise with the pegmatite dikes from the granite which cut it and the schists in all directions, and seldom follow the foliation. In the three small areas which we have mapped as granite, the rock is full of schist, ranging from mere films to bands many feet thick. These are all thought to be stretched inclusions, though it is seldom possible to demonstrate this. The bordering areas mapped as schist are likewise full of granite and pegmatite dikes, so that the mapping is highly conventional and merely roughly distinguishes areas in which granite is in excess from those in which the schist predominates. But the relations are much less simple and obvious than in the Thousand Islands region where what we regard as similar relations between Grenville and granite obtain. In passing across the Adirondacks from west to east the Precambrian rocks show a steady increase in complexity because of ever more severe metamorphism, until eventually, in the extreme east, the whole series has been so enormously compressed and stretched that it is no longer easy to recognize inclusions of sediments in igneous rocks, or dikes of igneous rocks in sediments, owing to the apparent interbanding.

There has also been much intermediate rock produced by a thorough interpenetration of the schist by the granite. The exposed granite masses are small, and we have not noted the evidence of the actual digestion of schist by granite, with production of rock of intermediate character, such as may be seen in the cases of the larger batholiths of Laurentian granite. There has been much injection of schist by granite, however, both along the foliation planes with production of injection gneiss, and also of the mosaic type in which the granite minutely penetrates the schist everywhere. In many bands of this type an enormous amount of garnet has developed.

The pegmatites. It was the abundant dikes of white granite pegmatite that first suggested the igneous nature of the white gneiss and furnishes the chief evidence for it, aside from the chemical composition. They cut through the granite everywhere and also

through the surrounding schists. Except for being usually more quartzose they are quite like the granite in mineralogy, coarsely crystalline aggregates of quartz and white feldspars (microperthite and oligoclase) with some biotite and often garnets. The schists just to the north of Saratoga, as shown along the Adirondack Railroad and along the north margin of Highland park, are full of these dikes; and a little farther north, along the fault scarp, the granite shows well and accessibly and has been quarried somewhat. In addition to the usual minerals these dikes show here and there other and rarer minerals. The old chrysoberyl locality, just to the north of Saratoga, is on one of these dikes in the schist. In this a lot of black tourmaline has developed, so that the pegmatite is a quartz-feldspar-tourmaline-garnet rock, in which frequent nests of chrysoberyl crystals occur. The dike cuts a hard mica gneiss and is about 3 feet wide at the old pit. One and one-half miles south of South Corinth is another old mineral pit on a pegmatite vein in schists, which furnished fine black tourmaline and rose quartz.

Mixed rock. With the exception of the pegmatites practically all the granite is contaminated with schist. We interpret this contamination as resulting from the shredding and dispersion of the schist inclusions in the granite under conditions of extreme pressure and metamorphism. All gradations occur between bands of schist somewhat impregnated by granite and granite that seems normal except for the fact that it may be somewhat more micaceous than it should be. This introduces an element of uncertainty in the attempt to investigate the granite chemically.

Chemical composition. The material chosen for analysis was obtained from the quarry in the granite on the face of the fault scarp 2 miles north of Saratoga, and was chosen because it was fresh and because contamination with schist seemed slight, if any. The thin section showed quartz, about 25 per cent, feldspars about equally divided between oligoclase on the one hand and microcline and microperthite on the other, about 70 per cent, and the remainder biotite, except for a few small zircons and a trifle of apatite and titanite. The hand specimen shows occasional garnets, none of which got into the thin section. The rock shows a rude banding due to variations in the amount of mica, suggesting a trifle of shredded schist in the more micaceous bands, but not enough to impair materially the value of Doctor Morley's analysis.

	1	2	3	4	5
SiO ₂	72.41	73.33	73.10	70.13	1.207
Al ₂ O ₃	13.85	13.55	14.29	15.47	.136
Fe ₂ O ₃	1.13	.58	1.04	1.52	.007
FeO	1.57	1.53	1.04	1.05	.022
MgO	.45	.45	.53	.85	.011
CaO	1.54	1.66	1.18	1.60	.028
Na ₂ O	4.31	5.01	3.08	3.72	.069
K ₂ O	3.68	3.12	5.36	4.39	.040
H ₂ O+	.41	.45	.54	.48	.....
H ₂ O — .....	.....	.....	.07	.01	.....
TiO ₂	.44	.17	.18	.30	.005
P ₂ O ₅	.07	.....	.03	.....	.0005
Cl .....	.....	.....	.03	.05	.....
F	.01	.....	.02	.09	.0005
S	.05	.....	.02	.07	.....
MnO	.33	.04	.07	.08	.004
BaO	.03	.....	.....	.05	.....
	100.28	99.89	100.58	99.86	

1 White granite (Laurentian?) from 2 miles north of Saratoga. E. W. Morley, analyst.

2 Laurentian granite gneiss from the Methuen bathylith of central Ontario. F. D. Adams, Jour. Geol., 17:17.

3 Laurentian granite gneiss of the Alexandria bathylith. E. W. Morley, analyst, N. Y. State Mus. Bul. 145, p. 176.

4 Laurentian granite gneiss of the Antwerp bathylith of northwestern New York, granite with slight amphibolite contamination. E. W. Morley, analyst, N. Y. State Mus. Bul. 145, p. 176.

5 Molecular ratios of analysis no. 1.

A comparison of the four analyses given brings out at a glance the practical identity of the Saratoga rock with those of Ontario and northwestern New York. They differ only in the alkali ratio, soda exceeding potash in the rock from Ontario, and the reverse being true in that from northwestern New York. In this respect the Saratoga rock is more like that from Ontario, though occupying an intermediate position. That this would be the case was indicated in the thin section, oligoclase being much more abundant and microperthite correspondingly less so than in the rocks from the Thousand Islands region. We regard the chemical evidence as strongly corroborative of the impression gained in the field regarding the igneous nature of this white gneiss.

The norm of the rock of analysis 1 is as follows:

Orthoclase	22.24	94.34	Class 1, persalane
Albite	36.15		Order 4, britannare
Anorthite	6.95		
Quartz	28.80		Rang 2, toscanase
Corundum	0.20		
Hypersthene	2.60	5.15	Subrang 4, lassenose
Magnetite	1.62		
Ilmenite	0.76		$K_2O : Na_2O :: 3 : 5.2$
Apatite	0.17		

The northwestern New York granites belong in subrang 3, toscano, while the Ontarian rock is a distinct lassenose. The Saratoga rock is on the border between the two subrang as the alkali ratio shows.

The rock differs considerably in appearance from the usual Laurentian granite of Canada and northern New York, the chief differences being the white color and the content of pink garnet. In the Thousand Islands region we have shown that the red Laurentian granites have their red feldspars bleached to white in the vicinity of Grenville limestones.¹ We have seen similar bleached granites in Ontario in like situation. About Saratoga the granite masses are small and suggest that erosion here is just beginning to uncover a granite batholith and has reached only a few of the higher protuberances, full of included rock masses. This might suggest that the granite would run into red rock in depth, but the matter is not urged since the chief inclosing rocks are schists which are poor in lime.

Because it gives rise to pegmatites and has the composition of a granite, this rock is regarded as igneous. It is further regarded as Laurentian for two reasons: first, because it is distinctly older than the syenite which cuts it intrusively just as it cuts the Grenville; and second, because it also shows its great age by the intricate manner in which it is involved with the Grenville and has been metamorphosed in common with it. In the latter respect it furnishes a strong contrast with the Laurentian granites of northwestern New York, whose relations with the Grenville are much less involved and more obvious. This contrast is to be attributed to the fact that the Precambrian rocks of the Adirondacks show a

¹ N. Y. State Mus. Bul. 145, p. 46-7, 177-180.

progressive increase in amount of metamorphism from west to east, so that, when the eastern border is reached, the relations of the rock groups to one another have become much disguised and difficult to decipher. If this white rock be really an igneous granite, then its relations to the Grenville are apparently just those which are diagnostic of the Laurentian in western New York and in Ontario. The apparently confused commingling of the two rocks, the apparent interbedding, and the abundant development of pink garnet both in the schists and in the intrusive, are the expression of the greater severity of metamorphism.

The syenite. The surface rocks of much of the Adirondack region are intrusive igneous rocks of early Precambrian age, but younger than the Grenville and the Laurentian. There are four groups of these rocks — anorthosite, syenite, gabbro and granite — named in order of age. The first two occur in much greater volume than the last two. In distribution, the anorthosite differs from the syenite in occurring chiefly in a single great bathylitic mass whose area at the present-day surface is about 1500 square miles in the eastern and central Adirondacks. There are small outlying masses to be sure, but neither abundant enough nor large enough materially to qualify the general statement. The southern edge of this mass is well north of the Saratoga quadrangle so that, except for an occasional glacial boulder, the rock is not found here.

The syenite contrasts quite sharply with the anorthosite in distribution. Instead of appearing in one huge mass it forms many small ones; instead of being an abundant rock in part of the region and wholly lacking in the remainder, it is found everywhere throughout the Adirondacks. Every detailed map of part of the region shows it present; and we know also that it is abundantly present in the remainder which has been covered merely by reconnaissance work. Because of this scattered distribution we are wholly unable as yet to give any estimate of any value concerning the area which the rock occupies; we can, however, now say that syenite is the surface rock of a much greater area in the Adirondacks than that occupied by anorthosite, large as the latter is, and that the area of syenite is a notable one when compared with any other known area the world over.

There are three main areas of syenite within the mapped limits. The largest is the one which forms the main mass of the Mt McGregor range and its back country. The modern gorge of the

Hudson cuts through this mass, some quarrying has been done in it to furnish masonry for Spiers dam, and hence the general exhibit of the rock along the river is the best to be found within the quadrangles. Up the hill west of Corinth is the southern half to two-thirds of another mass running north on to the Luzerne sheet; and the third area runs west from Lake Desolation and Mt Pleasant and its western extension may be seen on the map of the Broadalbin quadrangle.¹ It should be clearly understood that the boundaries between the syenite and the Grenville, as drawn on the maps, are of the most vague description. A multitude of dikes run out from the syenite into the Grenville; the syenite is full of inclusions of Grenville and the whole combination has been much deformed. There is plenty of syenite outside the areas mapped as such and there is much Grenville within the areas mapped as syenite. The best that can be done on maps of this scale is to endeavor to map as syenite, areas in which this rock constitutes more than 50 per cent of the whole, and as Grenville those in which the syenite constitutes less than 50 per cent.

The syenites have been described in detail, with chemical analyses in so many of the New York State Museum bulletins that it seems superfluous to repeat the discussion here.² As shown on the quadrangle, they are usually greenish gray rocks, sometimes blotched with red and grading into varieties richer in quartz and wholly red. The rock is thoroughly gneissoid. The most interesting thing about it is the way in which it uniformly runs over into coarsely porphyritic varieties at the margins and in the dikes of syenite in the Grenville. The porphyritic crystals, usually called augen, are often large, reaching a length of 2 inches, while those of an inch in length are very common; the feldspar of these augen is usually red, the augen are aligned parallel to the foliation, and in many cases are partly or wholly crushed or granulated. In the body of the rock, mica has developed in quantity and the resemblance to a metamorphosed conglomerate is strong. The rock is considerably more quartzose and acid than the main body of the syenite.

In the description of the Alexandria syenite of the Alexandria quadrangle, a similar porphyritic, marginal phase of the rock was described, but some doubt was expressed as to whether it was in

¹ W. J. Miller, map accompanying N. Y. State Mus. Bul. 153.

² Bul. 95, p. 312-40; Bul. 115, p. 512-25; Bul. 138, p. 44-52; Bul. 145, p. 182-84; Bul. 153, p. 14-21.

reality a marginal part of the same intrusion, or a separate intrusion.¹ The porphyritic border phases of the rock as they occur about Saratoga, where the relation to the main rock is certain, are so precisely like this porphyritic rock from Alexandria as to leave no doubt in our mind that this is also a border phase of the syenite intrusion. Such border phases of the rock, of porphyritic nature, are proving a quite normal feature of the syenite of the region.

The rock here varies about as it does elsewhere except that the more basic phases are lacking. Granitic varieties, however, are abundant. This seems to us likely due to the fact that the surrounding rocks in the quadrangle are mostly of siliceous nature. Much more than in the case of the other intrusives of the region there is found for the syenite a usual relation between the nature of its border phase and the character of the neighboring rock; such a relation as indicated by Kemp for the occurrences of the Elizabethtown quadrangle, and by the writer for the Long Lake quadrangle.²

But one variety of syenite on the quadrangle seems sufficiently novel to merit special notice. In the quarry by the Hudson near Spiers dam, is a very gneissoid dark green variety of syenite, one of the many varieties occurring there, which is really not a syenite at all, but diorite, 80 per cent of its feldspar being andesine (about Ab_3An_2). Pyroxene, hornblende, biotite, magnetite, apatite and zircon form about 15 per cent of the rock, some 7 per cent is quartz, and the remainder feldspar. The excellent exhibit of the rock shown in the quarry shows rapid and great range in composition, bands of granite, syenite and diorite appearing. All are plainly varieties of the one rock type. The material is almost precisely like the syenite at Little Falls in appearance and in variation, except that at Little Falls the variation between extreme types is not usually so rapid. In these very gneissoid syenites of the east, garnet is a more common mineral than in the mid-Adirondacks or on the west. There it is usually confined to the basic, border phases, or to the narrow dikes, whereas here it comes quite frequently as a constituent of the normal and the acid varieties.

Diabase dikes of late Precambrian age. Nearly everywhere in the Adirondacks all the other Precambrian rocks are found cut by

¹ N. Y. State Mus. Bul. 145, p. 39-40, 182-84.

² N. Y. State Mus. Bul. 138, p. 81; N. Y. State Mus. Bul. 115, p. 478-79.

dikes of unmetamorphosed, igneous rock. Their greater youth is shown by the fact that they cut all the other rocks. As all the other rocks have been more or less metamorphosed, and these have not, they are likely considerably younger. They are found in all parts of the region but most abundantly in Clinton county, on the extreme northeast, whence they diminish in number to the south and west. In the central and western Adirondacks they are comparatively scarce. On the extreme northwest, in the Thousand Islands region, they become again abundant. They are older than the Potsdam sandstone, the oldest Paleozoic rock of the region, and hence are of age intermediate between it and the other Precambrian rocks, and likely of late Precambrian age.

There are two chief varieties of these rocks: heavy, black traps, and less dense syenite rocks of red color. The latter have been so far found only in Clinton county, but the trap dikes range throughout the region. They are not particularly abundant in the Saratoga region, but those that do occur make up for their infrequency by their size. The usual trap dikes of the region range from 1 foot to 30 feet in thickness. Most of those near Saratoga are from 50 to 100 feet thick, and we have traced some of them for several miles. Thus the dike numbered 1 upon the Saratoga quadrangle, the one quarried for road metal north of the village, can be followed foot by foot for 2 miles north and south of the quarry, with an average width of from 75 to 100 feet. To the north it runs into low, swampy ground for 2 miles but beyond that and precisely on the trend of this dike we have repeatedly found a huge dike of the same width, for an additional distance of 7 miles more, which we confidently assume to be the same dike. Both to the east and west of this big dike are others which have been traced for several miles, and are 50 feet or more in width.

These are all ordinary diabases. Olivine has not been identified with certainty in any of them. They are labradorite, augite, magnetite rocks with good ophitic structure. All are considerably altered. It is exceptional to find the augite in fresh condition, and much of the feldspar is also altered. In this respect the dikes show sharp contrast with those of the northern Adirondacks where the larger number of the dikes are very fresh. This we attribute to the more vigorous glacial erosion on the north.

A table of analyses of Adirondack diabases has been recently published by Kemp, to which reference may be made by such as are interested in this subject.¹

STRUCTURES OF THE PRECAMBRIC ROCKS

Foliation. The foliation or cleavage, the most conspicuous structure of the Precambrian rocks, is found in sediments and igneous rocks alike, the trap dikes excepted. But the sediments are better foliated than the igneous rocks. The foliation of the Grenville rocks of the Saratoga region is parallel to the bedding, so that the directions of the two are equivalent. This seems to be the general relation of the two in the Adirondacks, as suggested years ago by Van Hise.²

The foliation strike over much of the Saratoga quadrangle is nearly east-west, and the dips are to the south and rather flat, seldom reaching 45°. The strike swerves to the northwest in the northeast portion of the quadrangle, and to the northeast in the northwest portion, though the dips remain to the south. This is not in accord with the usual direction in the Adirondacks where the prevailing strikes are northeast. As elsewhere a great monocline of the rocks is suggested; and, as elsewhere, this makes a Grenville succession of enormous thickness, so thick as to suggest caution in interpretation of the structure and as to emphasize the probability of the alternative suggestion that the rocks are closely pinched and folded, in a series of closed, overturned folds.

Faults. The great faults of the district are of much later date than the Precambrian, and dislocate Precambrian and Paleozoic rocks alike. But here, as elsewhere in the region, small faults are noted in the Precambrian rocks of such character that they seem surely of Precambrian age. We have found as yet no certain evidence of large faults of this early date.

PALEOZOIC ROCKS OF THE WESTERN TROUGH

BY H. P. CUSHING

The terms eastern and western troughs as used in this report have no significance other than convenience in description, and imply merely the relative positions of two contrasted sets of

¹ N. Y. State Mus. Bul. 138, p. 60-61.

² U. S. Geol. Surv. 16th Ann. Rep't, pt 1, p. 773.

Paleozoic formations. The western trough, which has been called the Chazy basin, was a subsiding trough which repeatedly was submerged beneath sea level during the early Paleozoic and received marine deposits, whose uneroded remnants still lie in comparatively undisturbed condition where they were deposited. In one or more troughs which lay farther to the east and were mostly quite separate from the Chazy basin, early Paleozoic deposits were also formed. These have since been greatly folded and faulted, and bodily overthrust to the west from their original position, upon the rocks of the Chazy basin. For convenience we here refer to them as the deposits of the eastern trough, without thereby meaning in any way to indicate that we necessarily regard them as deposits of an original single trough, rather than as of more than one. These rocks do not now lie where they were originally deposited and they are much more disturbed and folded than the rocks of the western trough.

The formations of the western trough, in order of age, are the Potsdam sandstone, Theresa formation, Hoyt limestone, Little Falls dolomite, Black River limestones (chiefly the Amsterdam limestone), basal Trenton shale and limestone (Glens Falls limestone) and Canajoharie shale. All these, with the exception of the Trenton shale and limestone, appear upon the map.

Surface upon which the western basin rocks were deposited. The old surface of Precambrian rocks, upon which the basal portion of the Paleozoic deposits rests in New York, has been shown by several observers to be an uneven surface, but yet not excessively uneven. The data are most easily obtainable on the west, since there the rocks are much less disturbed than on the east. On the southwest both Miller and Cushing have shown that this surface was exceedingly smooth, almost plane, with only a few scattered hillocks rising a few feet above the general level.¹ None have been observed rising higher than 50 feet above this level. On the northwest this surface is far less smooth, and consists of rapidly alternating elevations and depressions, with maximum differences of some 125 feet of altitude. The surface consists chiefly of slopes, and but little of it is flat.²

On the southeast, in the Saratoga region, the surface seems much as on the northwest. For the Broadalbin quadrangle Miller reports

¹ N. Y. State Mus. Bul. 126, p. 35; N. Y. State Mus. Bul. 77, p. 59-62.

² N. Y. State Mus. Bul. 145, p. 54-60.

similar results.¹ Contacts are few on the Saratoga quadrangle, but to the north of the village the basal Potsdam conditions are well shown for a distance of 4 miles along the Potsdam margin; and for a mile along the Hudson just below Corinth exposures of this horizon are excellent. The Precambrian surface on which the Potsdam rests is irregular. The more resistant bands of the Grenville and the igneous rocks stand above the mean level, as hillocks or ridges, while the weaker rocks are worn away to valleys or basins below mean level. Potsdam deposition began in the depressions, and as the sand accumulated it finally overtopped the elevations. There are differences of level of at least 75 feet, and probably more.

Assuming that the conditions of this surface on the northwest and the southeast (Thousand Islands and Saratoga regions) are substantially the same, as the evidence indicates, and that the surface on the southwest (Little Falls–Remsen) is much smoother, it would seem probable that in the opposite direction, on the northeast, it should be rougher. In that direction we lack the detailed work which might render the matter certain and can merely state that the impression given us by our reconnaissance work on the northeast is that it *is* rougher. We have seen Precambrian hills which project up into the Potsdam to the distance of 200 feet. From the data at hand we therefore conclude that the Precambrian surface under the Potsdam is least smooth on the northeast (Clinton county), and that it steadily increases in smoothness toward the southwest. The northwest and the southeast are about equidistant from these and should be expected to show about equal character of surface, as they do.

CAMBRIC PERIOD

General statement. The formations of Cambrian age belonging to the western basin and found within the mapped district, are the Potsdam, Theresa and Little Falls formations, the Potsdam a sandstone, the Theresa a series of passage beds of alternating sandstone and limestone or dolomite, and the Little Falls a dolomite formation. Between the Theresa and Little Falls in the near vicinity of Saratoga is a more calcareous formation which we call the Hoyt limestone, which is probably best regarded as an upper member of the Theresa formation.

According to prevailing present-day classification, these formations are of Upper Cambrian age. They also belong in the new system, Ozarkic, which Ulrich is proposing to establish between

¹ N. Y. State Mus. Bul. 153, p. 50–52.

the Cambric and Ordovician of former classifications. Whether the Ozarkic is ultimately given the rank of a system or is regarded simply as a series forming the uppermost division of the Cambric, does not concern us here; but rather the fact that the above-listed formations are of Ozarkic age.

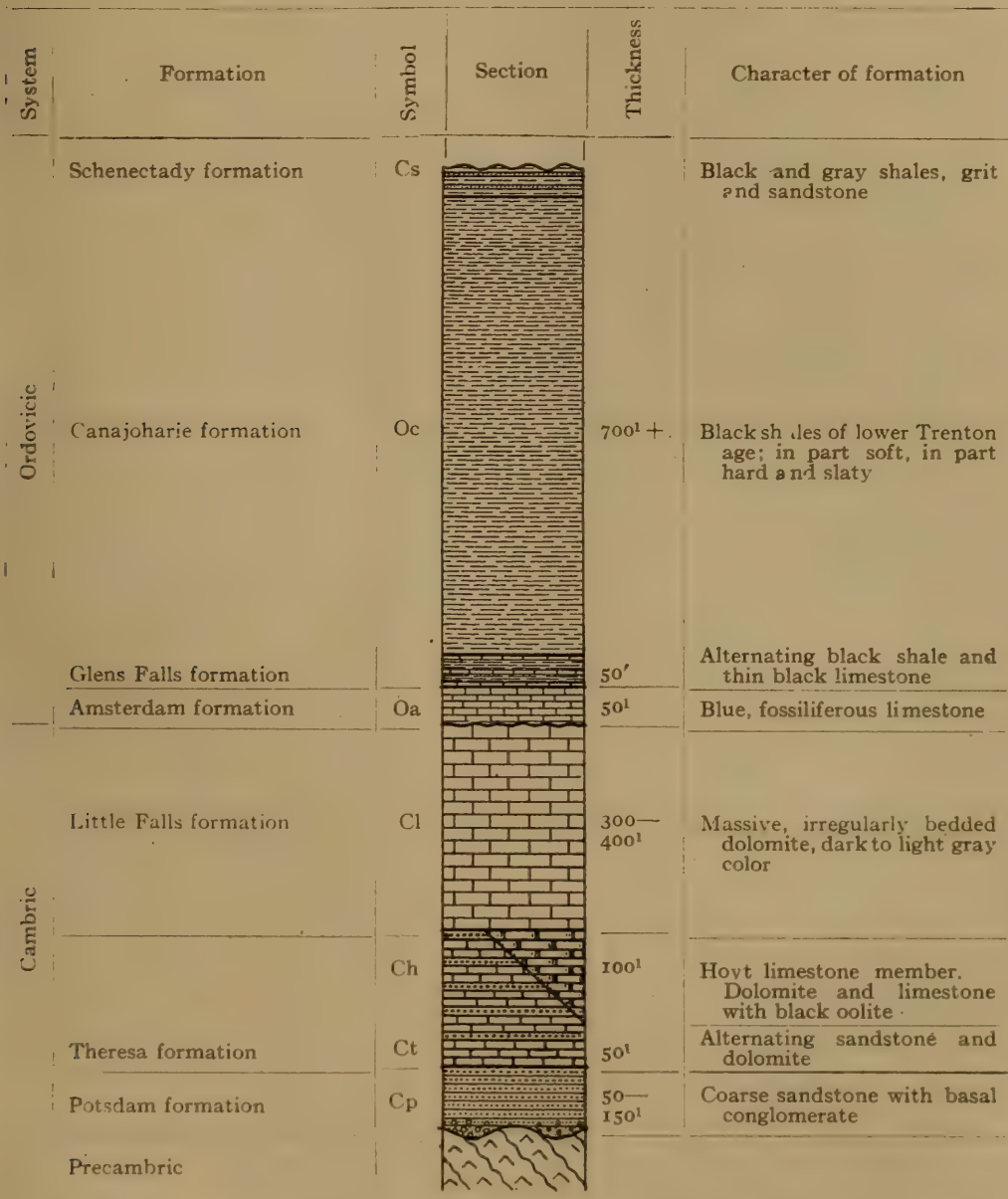


Fig. 3 Generalized columnar section of the rocks of the Saratoga quadrangle, and of the western portion of the Schuylerville quadrangle.

POTSDAM SANDSTONE

After an enormously long period of existence as a land area, whose duration comprised all the latter portion of Precambrian time and most of the Cambrian as well, and whose history is recorded in erosion of the Precambrian rocks, the eastern margin of the Adirondacks became depressed and deposits commenced to accumulate upon its surface. Thus began the formation of the Potsdam sandstone.

The deposit began on the northeast and extended both west and south, accumulating in sinking troughs along the line of the Champlain and St Lawrence valleys. It is thickest in Clinton county, where the thickness is an unknown amount in excess of 1000 feet and where the lower beds are unlike those shown elsewhere. These beds are coarse conglomerates, feldspathic sandstones and ferruginous, shaly sandstones, wholly without fossils and apparently deposited above sea level. They are followed above by purer, quartz sandstones, white, gray, yellow, brown or red in color, mostly very thoroughly cemented and resistant rocks. Above come less firm, somewhat calcareous sandstones, forming the upper part of the formation. In this upper division and in the upper part of the preceding division a scant fauna appears which shows that this portion of the formation is marine.

It is only this upper division of the formation which is found in Saratoga county. The thickness here does not average in excess of 100 feet, ranging from 50 to 150 feet, the variations being chiefly due to the irregularity of the Precambrian surface upon which it was deposited. There is usually found a few feet of basal conglomerate, seldom very coarse, above which the formation is unbroken sandstone, the lower half siliceous, the upper calcareous, in which many of the beds weather to an ochreous rotten stone. No fossils were seen by us in the formation on the Saratoga quadrangle, though Miller found *Lingulepis acuminata* in it on the adjacent Broadalbin quadrangle.

About Saratoga the most extensive exposures of the formation are those north of the village in Greenfield township. It is also thinly exposed at Corinth. The best continuous section is exposed along a small branch of Glowegee creek, a mile south of East Galway. At the base of the section the creek cuts down into the Precambrian, exposing a small outlier of this formation. Above this a continuous section 200 feet thick is exposed. The lower 50 feet is chiefly sandstone, with occasional beds of calcareous sandstone; in

the next 50 feet sandstone and calcareous sandstone alternate, with an occasional bed of blue, sandy dolomite in addition. The upper 100 feet consists of alternations of all three. This we definitely assign to the Theresa formation. The lower 100 feet we assign to the Potsdam, notwithstanding the presence of an occasional dolomite bed. There is never any sharp boundary between the two formations.

THERESA FORMATION

Everywhere in New York where the Potsdam sandstone occurs, it is united with the formation next above, usually a dolomite formation, by a series of intermediate or passage beds which consist of alternating sandstone, calcareous sandstone and dolomite. These passage beds differ from the sandstone beneath and the dolomite above, are sufficiently thick to require mapping as a separate formation, as such require a name, and we are calling them the Theresa formation.¹ The sandstone is in excess in the lower part of the formation, and the dolomite in the upper. Deposition was apparently continuous but physical conditions slowly changed, the sand supply from the Adirondack land slowly diminishing and finally being entirely cut off. Because of this it is impossible sharply to delimit the formation, either at base or summit. In what we here class as upper Potsdam there is an occasional bed of dolomite, and a few stray beds of sandstone run well up into the overlying dolomite formation. Nevertheless there is a sufficient thickness of mingled sandstone and dolomite, about which there could be no possible difference of opinion, to justify its separateness as a formation.

In the general region the Theresa formation has a thickness of from 150 to 200 feet. Thus Miller gives its thickness as 200 feet on the Broadalbin quadrangle, while our measured sections at Whitehall and at Ticonderoga show a thickness of at least 150 feet. There is at least 150 feet of it in the section south of East Galway, on the Saratoga quadrangle, and the full thickness is not there exposed. In all these localities the formation consists of alternating beds of hard, vitreous sandstone, weak calcareous sandstone and sandy blue dolomite, with *Lingulella acuminata* as its most abundant and characteristic fossil.

West and northwest of Saratoga, in Greenfield township, the section differs. Instead of a thickness of 150 to 200 feet, the

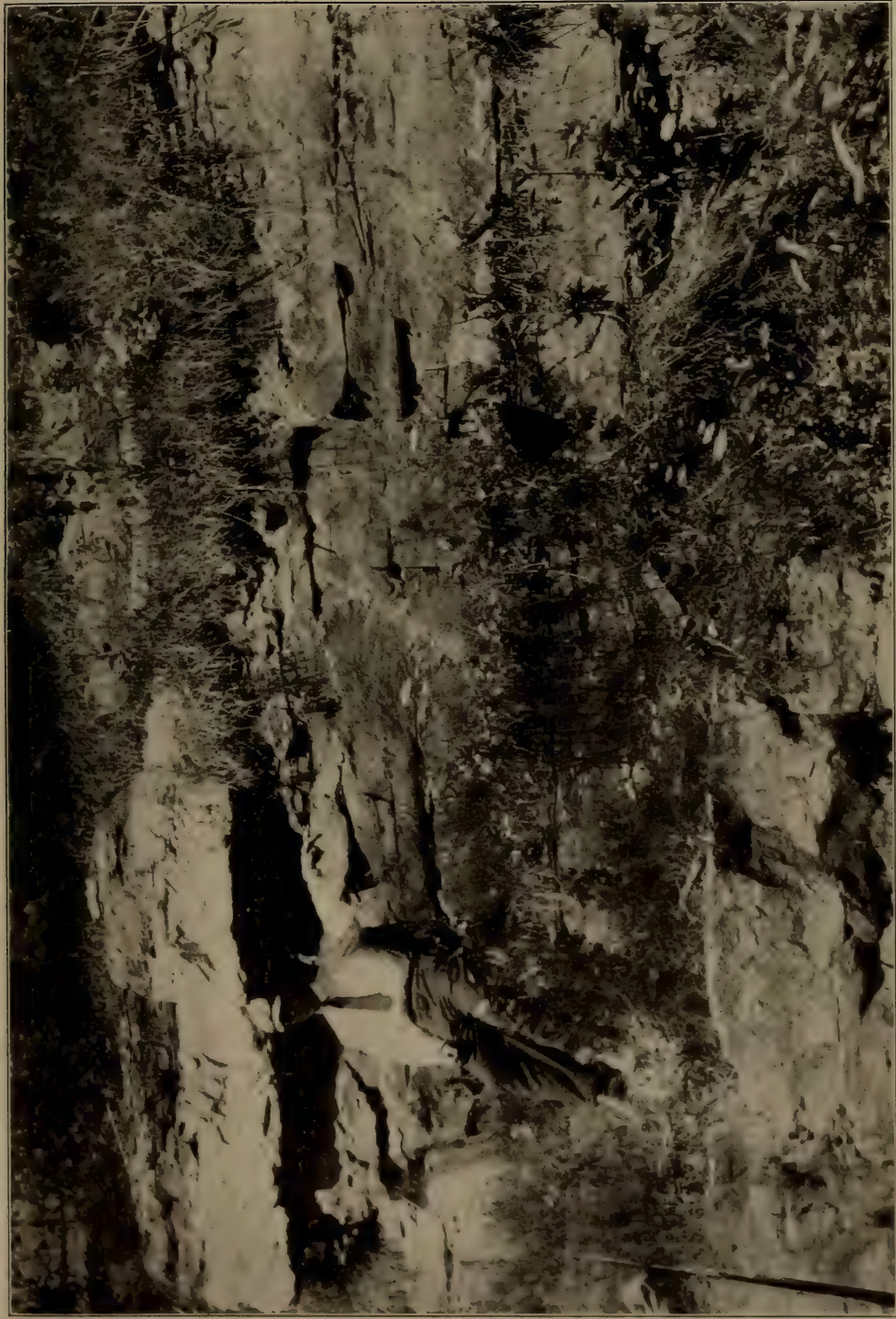
¹ N. Y. State Mus. Bul. 145, p. 64-66.

Theresa formation is only 50 to 75 feet thick and is overlaid by a limestone formation, some 100 feet thick, which contains but little interbedded sandstone and is quite fossiliferous. This seems to us on the horizon of the upper portion of the Theresa of the sections north and west, and we therefore classify it as a member of the Theresa formation.

The rock cuts along the Adirondack Railroad, northwest of Saratoga, together with quarries to the south of the railroad, furnish us with the best section of this phase of the Theresa formation and of the Potsdam beneath. The section has already been published, and is here reproduced.¹

	FEET	INCHES
22 Rocks concealed between two railroad cuts; boundary between Theresa and Hoyt limestone member in the interval; thickness about.....	20	....
21 Rotten, brown, calcareous sandstone; blue when fresh.....	....	8
20 Hard, vitreous, light colored sandstone, banded with narrow streaks of darker, calcareous sandstone.....	2	4
19 Thin bedded, blue, calcareous sandstone, weathering brownish.....	....	9
18 Blue black, oolitic dolomite, frequent rounded quartz grains, many small drusy cavities.....	1	3
17 Blue, calcareous sandstone, weathering light colored, upper portion shaly.....	1	8
16 Hard, light colored, vitreous sandstone.....	1	6
15 Thin bedded, calcareous sandstone, somewhat oolitic, blue when fresh but rapidly weathering brown, mottled and crumbly, many drusy cavities with calcite and quartz crystals; abundant trilobite fragments, the lowest zone of these so far discovered in the Saratoga region.....	1	3
14 Light colored, vitreous sandstone.....	2	5
13 Bluish, nodular, finely crystalline dolomite, with a slight amount of calcite cement, shaly at base and summit, frequent nodules of crystalline calcite; holds <i>Lingulepis acuminata</i>	2	3

¹ N. Y. State Mus. Bul. 140, p. 111-12.



L. P. Cushing, photo, 1910

Alternating sandstone and dolomite of Theresa formation in railroad cut, 3 miles west-northwest of Saratoga. The outstretched hand is resting on the trilobite layer, no. 15 of the section. Beds 12 to 17 are shown in the view.

	FEET	INCHES
12 Light colored, vitreous sandstone.....	1	3
11 Gray, banded sandstone, slightly calcareous.....	3	9
10 Alternating calcareous sandstone and crystalline dolomite of blue gray color, large nodules of crystalline calcite in the latter; base of cut.....	3	....
9 Concealed between this and next cut east; arbitrary boundary between Theresa and Potsdam in the interval; about.....	30	....
8 Hard, vitreous, light colored sandstone with darker calcareous sandstone above and below..	1	8
7 Concealed to brook exposures next east; about...	30	....
6 Light colored, vitreous sandstone, with alternating layers of darker, calcareous sandstone which weather rapidly	30	....
5 Light colored, vitreous sandstone.....	15	....
4 Concealed.....	4	....
3 Light colored, vitreous sandstone.....	2	....
2 Concealed.....	4	....
1 Conglomerate, increasing in coarseness downward and reaching nearly to base of formation.....	10	....

Numbers 1 to 8 are regarded as constituting the Potsdam though there is some question about the classification of 7 and 8, which may be Theresa. If they are regarded as Potsdam, that formation has a thickness of 96 feet, 8 inches in the section, with the base not reached, though it can not be more than a few feet away. Above is a thickness of 52 feet of beds which are certainly to be classed as Theresa, and occasional beds of sandstone run still higher.

The State road out of Saratoga toward Corinth crosses the Adirondack Railroad in a low depression between two rock cuts. The easterly one of these is the one in which the upper part of the above section was measured, nos. 10 to 21. It is the most accessible locality within the district about Saratoga where the Theresa formation is well shown. A photograph of the rock wall of the cut is shown in plate 1, the extended hand resting on the fossiliferous layer, no. 15 of the section. From this we obtained species of *Ptychoparia* and *Agraulos* which are specifically different from the forms found in the Hoyt limestone above. The species collected here were, in addition to *Lingulella*

(*Lingulepis*) *acuminata*, *Agraulos* sp. nov.¹ and *Ptychoparia matheri* Walcott.

HOYT LIMESTONE MEMBER

In 1879 Dr C. D. Walcott first described an Upper Cambrian fauna from limestones of that age in the vicinity of Saratoga, and made frequent reference to the same fauna and beds in subsequent publications.² In 1899 Clarke and Schuchert first assigned a name to this formation, calling it the Greenfield limestone.³ This name, however, was preoccupied having been previously assigned to a limestone of Silurian (Monroe) age, in central Ohio. A new name had therefore to be assigned, and yet no suitable one seemed forthcoming. The known exposures of the formation are all in Greenfield township, and the villages in the township all bear the name of Greenfield, in so far as they are located on the formation. There are no good exposures of the formation along any watercourse whose name could be utilized. The name Saratogan was preoccupied. Under the circumstances there seemed no alternative but to apply to the formation the name of the quarry at which it is best and most fully shown (plate 2). The name of the quarry has already appeared in geologic literature, in papers by Hall, Walcott and Prosser.⁴ Unfortunately the farm has changed hands and the quarry is no longer locally known as the Hoyt quarry. But no other name suggests itself as suitable, and we are therefore proposing the name Hoyt limestone for the formation, at the same time indicating the location of the quarry upon the geologic map.

In an earlier paper by Ulrich and Cushing this Hoyt limestone was made a basal member of the Little Falls dolomite, the next formation above.⁵ More strictly, however, it seems a phase of the upper portion of the Theresa formation, the thickness of the Theresa and Hoyt together, in the vicinity of Saratoga, about equaling the thickness of the Theresa alone north and west of Saratoga;

¹ Regarding this Dr C. D. Walcott writes Doctor Ruedemann this form is "very closely related, if not identical with a species of *Agraulos* which I have marked as a new species from the upper beds of the St Croix sandstone of Wisconsin."

² N. Y. State Mus. Nat. Hist. 32d Ann. Rep't, p. 129-31; U. S. Geol. Surv. Bul. 81, p. 346-47.

³ Science, December 15, 1899.

⁴ N. Y. State Mus. Nat. Hist. 36th Ann. Rep't, pl. 6, description; Science, 1884, 3:137; N. Y. State Mus. Bul. 34, p. 478-79.

⁵ N. Y. State Mus. Bul. 140, p. 129.



Hoyt limestone at Hoyt quarry, showing the lower 16 feet of the 25 feet of the quarry section. The massive central bed, nearly 5 feet thick, is noteworthy.

H. P. Cushing, photo, 1919

while the Little Falls dolomite at Saratoga has about the same thickness as it has to the west and north. Miller has already made a similar suggestion.¹

The Hoyt limestone is composed of alternating beds of dolomite and of limestone, and is comparatively thick bedded. The color is usually dark and often black. Several beds of black oolite occur, chiefly in the lower portion of the formation. Many of the limestone beds furnish abundant fossils, chiefly trilobites in very fragmentary condition. Along with these are small gastropods, which are much less abundant. *Lingulella acuminata* occurs everywhere. Perhaps the most striking fossils of the formation are the big, reeflike masses of the organism of unknown nature, known as *Cryptozoon*. The genus was originally described by Hall from the exposures by the roadside just north of the Hoyt quarry (plates 3 and 4), where a bared and glaciated surface of the rock is splendidly exposed over a considerable area. Reefs and masses of more than one species of this genus are of common occurrence in both the Hoyt limestone and the overlying Little Falls dolomite, in the latter ranging throughout the Mohawk and Champlain valleys. The reeflike nature of the masses is well shown in many places in the district, notably so perhaps in the railroad cut just east of Greenfield depot. Midway of this cut is shown a *Cryptozoon* reef of massive limestone (6 feet thick). Toward the west this bed breaks up into thinner bedded material which at the same time becomes very sandy and with layers of nearly pure quartz sand, while to the east it remains pure limestone, though the *Cryptozoon* gives out. The east is taken to be the seaward and the west the landward side of the old reef.

The Hoyt limestone is well shown in the so-called railroad quarry, 1 mile north of Saratoga (plates 5 and 6). But neither base nor summit shows there and the outcrop is an isolated one lying between two branches of a fault, so that it tells nothing whatever in regard to the stratigraphic relations of the formation. It has a local high dip to the southwest due to proximity to a fault, shows a thickness of some 20 feet of the formation including a splendid *Cryptozoon* reef, and is an excellent locality for fossils. But for the stratigraphy we must go to the exposures in the railroad cuts and the vicinity of the Hoyt quarry. Here an excellent section of the greater part of the formation is obtained, overlying the Theresa formation, hence making certain its stratigraphic position. The summit, however, is not seen, though if we are correct in

¹ N. Y. State Mus. Bul. 153, p. 30.

assigning the exposures at the crossroads at South Greenfield to the base of the Little Falls dolomite, then the section closes in beds not far from the top. The section has already been published and is here repeated, numbered in continuation of the Theresa section already given.

	FEET INCHES	
40 Exposures at Hoyt quarry: hard, blue to black, subcrystalline to crystalline magnesian limestone, largely of dolomite rhombs with calcite cement; 1 foot from the top is a Cryptozoon reef bed, and the section rests on another such bed, which is the same as the one shown by the roadside (plates 3 and 4); the rock is partly thin and partly thick bedded; some of the layers show coarsely crystalline calcite cement, giving large glittering cleavage faces on freshly broken surfaces; trilobites, gastropods and Lingulella are found throughout.....	25	....
One-third of a mile north of the Hoyt quarry is another quarry face by the roadside, capped by the same Cryptozoon layer which forms the base of the Hoyt quarry section, but was not included in the 25 feet of that section.		
39 Dark blue, subcrystalline, magnesian limestone full of Cryptozoon; frequent black, oolitic grains	1	5
38 Massive beds of blue, finely crystalline, magnesian limestone, with occasional sand grains; trilobite fragments	5	5
37 Thin bed of calcareous sandstone, weathering to brown, rotten stone.....	....	5
36 Two beds of dark blue, crystalline, magnesian limestone with some sand grains.....	2	5
35 Layer of dark gray, calcareous sandstone.....	1	7
34 Light colored, vitreous sandstone with films of darker, calcareous material.....	1	3
33 Dark colored sandstone with calcareous cement... ..	....	4
Four-tenths of a mile northeast of this are two considerable cuts along the railroad in which the following section is shown (plate 7). The hiatus is estimated at.....		
	20	....



Cryptozoon proliferum Hall. Glaciated exposure of one of the Cryptozoon reef beds of the Hoyt limestone, by the roadside near the Hoyt quarry. Original locality of Hall's figure of the species.

H. P. Cushing, photo, 1910



Another view of the Cryptozoon surface, same locality. Both views show foreshortening due to down-pointing of the camera.

H. P. Cushing, photo, 1910

	FEET	INCHES
32 Dark blue, subcrystalline, magnesian limestone. . . .	1	3
31 Blackish, oolitic dolomite.	1	8
30 Dark blue, crystalline dolomite, calcite cement which shows large cleavage faces; holds <i>Lingulepis acuminata</i> . . . . .	....	10
29 Black, oolitic dolomite containing pebbles of mud limestone	1	8
28 Rotten, crystalline dolomite, calcite cement rapidly leaching out . . . . .	....	5
27 Blackish, oolitic dolomite in three beds, the upper a <i>Cryptozoon</i> bed; frequent sand grains and many drusy cavities with quartz and calcite crystals	2	6
26 Easily rotting crystalline dolomite, calcite cement, very shaly above. . . . .	....	9
25 Hard, light colored, vitreous sandstone.	1	4
24 Crystalline bluish dolomite, calcite cement.	1	7
23 Two massive beds of blackish, subcrystalline mag- nesian limestone, with frequent sand grains.	4	3
22 Concealed between the two railroad cuts; boundary between Hoyt limestone and Theresa formation in the interval.	20	....
	94	1

Several points brought out by this section need to be noted. Vitreous sandstones run up in it for nearly 60 feet above the base, and there may be some question in regard to the classification of this portion of the section. The sandstones are not so numerous as in corresponding portions of the Theresa section elsewhere; the black oolitic and magnesian limestone beds are quite characteristic of the Hoyt, and not so much so of the normal Theresa. The section brings out clearly the fact that the Hoyt lies above the Theresa passage beds and is followed by the Little Falls and that the same interval elsewhere is occupied by a thickness of passage beds equal to the combined thickness of the Hoyt and Theresa of the Saratoga section. In other words, the Hoyt is a local phase of the upper Theresa, probably a more offshore phase. It is exposed only at Saratoga because only here has erosion cut down to this phase. Elsewhere the near shore phase of the formation is exposed and

the extension of the Hoyt lies to the east and south of Saratoga, buried from sight beneath the younger rocks which cover it in those directions. The waters were clearer, less subject to incursions of sand, *Cryptozoon* reefs flourished as they did not in the normal Theresa, and trilobites and gastropods lived on the surface of the reefs, where we find their fossil remains abundantly today.

To the thickness of the Hoyt limestone as here measured there needs to be added an unknown amount which we estimate as probably not over 25 feet, in order to reach the summit of the formation.

From the Hoyt limestone we collected the following fauna: *Cryptozoon proliferum*, *Lingulella* (*Lingulepis*) *acuminata*, *Triblidium cornutaforme*, *Matherella saratogensis*, (*Murchisonia*) sp. indet., *Matthewia variabilis*, *Pelagiella hoyti*, *P. minutissima*, *Agraulos saratogensis*, *Lonchocephalus calciferus*, *Dicellocephalus hartti*, *D. tribulis*.

LITTLE FALLS DOLOMITE

General statement. The name "Calciferous" was originally applied to the considerable thickness of dolomitic rocks which overlies the Potsdam sandstone in the Champlain and Mohawk valleys. Later on Clarke and Schuchert replaced this by the name Beekmantown, and to the rather unfossiliferous phase of the formation in the Mohawk valley gave the local name of Little Falls dolomite. Brainard and Seely were the first carefully to measure and subdivide the formation in the Champlain valley, making five subdivisions which they lettered from A to E.¹ Recent work of Ulrich, Ruedemann and Cushing showed that the Little Falls dolomite of the Mohawk valley was the equivalent of division A and the lower part of division B of the Champlain Beekmantown, and that divisions C, D and E were absent along the Mohawk; furthermore that an unconformity everywhere separated the Little Falls from the overlying Beekmantown, and that the natural affiliations of the former were with the Potsdam and Theresa beneath, rather than with the Beekmantown above, both structurally and faunally.² In the Saratoga region the Little Falls is present and the Beekmantown wholly absent. The lowest division of the Beekmantown,

¹ Am. Mus. Nat. Hist. Bul. 3, p. 1.

² N. Y. State Mus. Bul. 140, p. 97-140.



Railroad quarry in Hoyt limestone, 1 mile north of Saratoga, looking northeast, showing the railroad cut and the quarry to the west. The beds are the same as those at the Hoyt quarry.

H. P. Cushing, photo, 1910



North end of the quarry shown in plate 5, looking northwest and showing the strong southwesterly dip.
H. P. Cushing, photo, 1910

the Tribes Hill limestone, may have been deposited here and later removed by erosion. The remainder of the Beekmantown was probably never deposited about Saratoga or along the Mohawk.

Description. The Little Falls dolomite is composed chiefly of rather massive beds of gray dolomite. The larger part of the formation consists of dark gray, fine grained beds. Many of these contain some calcite, chiefly as a cement binding the dolomite crystals together. On weathered surfaces the dolomite is the more resistant of the two, the calcite is dissolved, leaving somewhat projecting dolomite crystals and giving a porous, sandy appearance to the weathered surface. Beds of this type are best exposed along North Broadway as the road climbs the hill south of St Clements.

In addition there is a considerable thickness of more coarsely crystalline, lighter colored dolomite in the formation. About Saratoga such beds form the summit of the formation and are exposed in many places, perhaps best in the Maple Avenue quarry. They are, in general, quite pure dolomite, lacking the calcite cement which occurs so generally in the darker beds (plate 8).

It is impossible to get any very correct idea of the thickness of the Little Falls dolomite, from the exposures of the quadrangle. There is not sufficient variation in the character of the rock to enable one to assign the beds of the scattered exposures to their proper horizon in the formation; and faults so abound that nothing like a continuous section of the entire formation exists in the region. At Saratoga Springs the exposures are in a triangular fault block, and the exposed thickness is 119 feet.¹ This is the upper portion of the formation and gives no clue to the amount beneath which is lacking. Two deep wells have been drilled at Saratoga with the diamond drill, with careful preservation of the drill cores, one at the Congress and the other at the Hathorn spring. We have had the opportunity to study the former, though we have unfortunately not been able to see the latter. Each well went down near the Saratoga fault, and each must rest under the suspicion of having crossed a small branch of the fault in such way as to duplicate part of the well section and increase the apparent thickness. In the Congress well 18 feet, 2 inches of drift was passed through, then 18 feet, 7 inches of Amsterdam limestone, after which the entire core of the well, some 281 feet, consisted of Little Falls dolomite. The upper 40 feet of this was of the characteristic coarsely crystalline, light colored dolomite which forms the upper part of the formation about

¹ N. Y. State Mus. Bul. 140, p. 108-9.

Saratoga. Beneath this was 180 feet of darker colored dolomite of varying grain, the upper and lower portions through a thickness of some 50 feet each coarser than the center. The upper part had many nodules of crystalline calcite. Underneath this was a recurrence of coarse, light colored beds. This gave rise to the suspicion that perhaps a fault was crossed here causing a reappearance of the upper beds of the formation. But no suggestion of a fault was given in the appearance of the drill core, and a careful comparison of this portion with the upper portion did not show any exact correspondence. There was also a greater thickness of the coarse beds here than above. Below, dark beds came in again and the well terminated in these. If this section is really unbroken, then the thickness of the formation is certainly 300 feet and may be considerably more.

The Hathorn well was 1006 feet deep. After 62 feet of drift the drill entered the Amsterdam limestone. The bottom 231 feet were reported as Potsdam, but the thickness suggests that the Theresa is also included and perhaps the basal Hoyt. Assuming it to represent Potsdam and Theresa, and deducting this thickness and the drift thickness from the total of the well, leaves yet a thickness of over 700 feet for the combined Amsterdam, Little Falls and Hoyt formations. If the bore does not cross a fault this would mean a thickness of from 500 to 550 feet for the Little Falls which is considerably in excess of any known thickness elsewhere possessed by the formation. It is doubtful if it exceeds 350 feet in the Saratoga region, though it may reach 400, which is as great a thickness as it is known to reach at any point.

There is much chert in the formation. Black chert is the most abundant but gray chert is by no means uncommon. The upper beds of the formation are heavily charged with chert in nearly all localities throughout its extent, and Saratoga is no exception to the general rule. The upper bed at the Maple Avenue quarry is full of chert. The lower beds of the formation are also heavily charged with it. These beds are best seen about a mile south of Porter Corners.

The formation is everywhere exceedingly unfossiliferous. *Lingulella acuminata* is occasionally found in the lower beds and a few fossils are sometimes to be seen in the upper cherts. The most common fossil, however, is *Cryptozoon*, reefs of which occur throughout the formation. This is the only fossil which we have seen in the formation about Saratoga. In most of the formation the



Potsdam sandstone in 30 cut on Adirondack R. R.



Upper beds of Little Falls dolomite in cliff back of High Rock spring, Saratoga. The cliff face is the fault scarp of the upthrow side of the Saratoga fault.

H. P. Cushing, photo, 1910

Cryptozoon is *C. proliferum*, but in the upper beds another and quite different species comes in. A bed of dove limestone which occurs capping the upper, light colored dolomite to the west of Saratoga, exposes this Cryptozoon most excellently (plates 9 and 10). The same species occurs at the summit of the formation at Ticonderoga and elsewhere. The summit beds are usually full of chert and the Cryptozoon is often heavily silicified.

Unconformity at the summit of the Little Falls. The Little Falls dolomite is directly overlaid, in the Saratoga region, by the Amsterdam limestone of upper Black River age. No representatives of the Beekmantown and Chazy groups appear in the section, and the lower beds of the Black River group are also lacking. The Tribes Hill limestone, which overlies the Little Falls in the Mohawk valley and is of probable lowest Beekmantown age, is absent about Saratoga. It may have been thinly deposited and subsequently eroded. It seems quite safe to say that the Beekmantown and Chazy deposits never reached the district, and that the lower Black River rocks were laid down but thinly if at all.

Aside from the absence of these rocks from the region, the physical evidence of the unconformity is twofold. The base of the Amsterdam rests on quite different beds of the Little Falls, at the various exposures of the contact, indicating erosion of the surface prior to Amsterdam deposit; and the basal bed of the Amsterdam varies from place to place, showing that the surface upon which it was laid down was irregular and that the lower beds of the Amsterdam are only found in the old depressions. Furthermore the Amsterdam begins with a basal conglomerate full of Little Falls pebbles. This basal layer is best seen at Saratoga. In the northern part of the village, just west of the fault line and just north of where the Delaware & Hudson Railroad crosses the fault, thin patches of this conglomerate may be seen resting on the upper surface of the Little Falls, proving that it is the very top of that formation which there forms the upthrow face of the fault.

AMSTERDAM LIMESTONE

In the sections of the eastern Mohawk region there appears, beneath the rocks which are strictly referable to the Trenton group, a thin limestone formation which is wholly distinct from anything found in the vicinity of Trenton Falls and which we regard as an upper member of the Black River group and are calling the Amsterdam limestone. A detailed account of the formation in the type

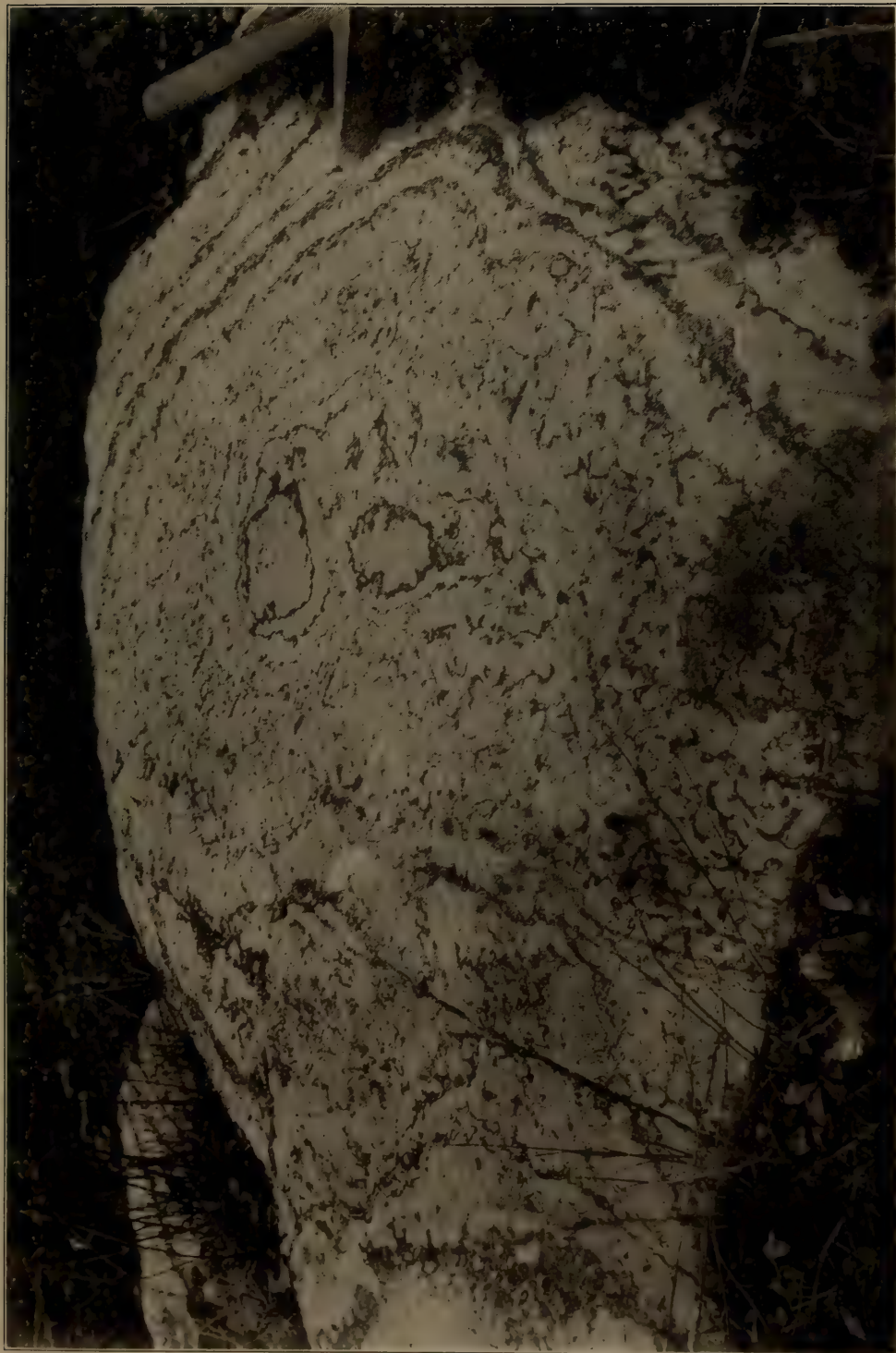
region has not yet been published, but it is hoped that it will soon appear. A preliminary statement concerning it has already been made.¹

Within the Saratoga quadrangle this limestone is seldom exposed, owing to heavy covering of glacial drift. The best and most complete section of it is at Rock City Falls, where the contact with the underlying Little Falls dolomite is exposed. At Saratoga the base is thinly exposed and a wedge of the formation is infaulted along the Saratoga fault, exposed back of the Star spring and for a short distance northward. There is a good exposure at Rowlands mill, which, however, does not show the base; and there are other exposures through North Milton, the best folded into a little syncline. There is also a small exposure of basal Amsterdam and summit Little Falls, drop-faulted along the West Galway fault, south of East Galway. Nowhere within the quadrangle has the summit been seen exposed, except perhaps at Rowlands mill.

The best section and the one exposing the lowest beds, is that at Rock City Falls (plate 11). The section here had been previously measured by Prosser.² There is some 14 feet of Little Falls dolomite in the face of the fall, gray, finely crystalline dolomite for the most part, full of black seams, occasional nodules of crystalline calcite, and with much chert midway. The horizon seems beneath that of the coarser, light colored beds, such as form the summit about Saratoga, and they have likely been removed by erosion. The contact shows slight irregularity, as it does at Saratoga. The lower 3 feet of the overlying beds have a look of the Lowville and were referred to that formation by Prosser. We collected some fossils from them, however, which seemed to belong to the Amsterdam, though we are somewhat in doubt in the matter. If this be Lowville it is the only occurrence of this formation seen within the quadrangle limits. Above follow 38 feet of Amsterdam, somewhat thin-bedded, crystalline fossiliferous limestone of blue color. Not only are the Lowville-looking beds absent elsewhere but the succeeding 15 feet is also absent in the North Milton sections, the higher beds resting directly on the Little Falls there. At Rowlands mill and in the North Milton sections the summit shown is thinner bedded and likely above anything in the Rock City Falls section. About North Milton are a half dozen exposures, chiefly pinched into a little syncline with the upper Little Falls, as shown on the areal map.

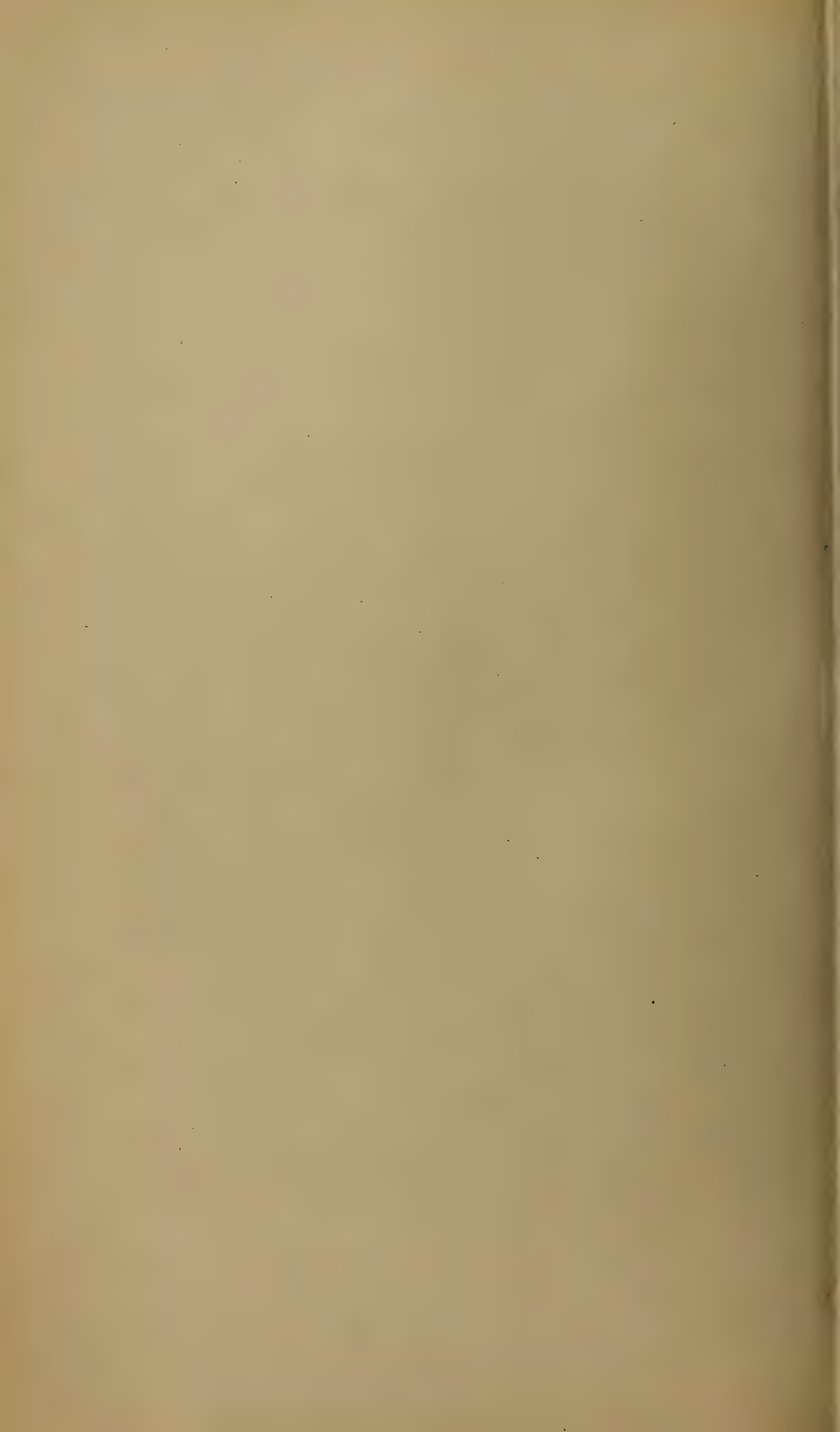
¹Am. Jour. Sci., 31:143.

²N. Y. State Mus. Bul. 34, p. 476.



Glaciated surface of *Cryptozoon* at summit of Little Falls dolomite, 4 miles west of Saratoga. This is a different species from the *C. proliferum* shown in plates 3 and 4 and is a characteristic form in the upper Little Falls dolomite.

H. P. Cushing, photo, 1911





H. P. Cushing, photo, 1911.

Another portion of the Cryptozoon reef shown in plate 10; in the background appears the exposure shown in the previous view; the picture was taken just after a shower and the dark patch is a portion of the surface that had not yet dried.

Since the actual summit nowhere shows, we are somewhat in doubt as to the actual thickness of the formation and as to what directly overlies. The many drilled wells to the south of Saratoga aid in supplying the information. Underneath the Canajoharie shale these wells show an average thickness of from 40 to 45 feet of alternating shale and limestone, beneath which comes 35 to 40 feet of limestone and then the Little Falls. The limestone is Amsterdam. Whether any of the alternating shale and limestone is also to be classed as Amsterdam we do not know. We have seen but one exposure of the horizon, in a cut by the roadside a mile east of Rock City Falls, an exposure so poor as really not to merit the name. The fauna was Trenton, not Amsterdam; but the exposure may not have been basal. We incline to the opinion that this alternating shale and limestone is all Trenton, and that the thickness of the Amsterdam is from 40 to 60 feet, varying with the irregularity of the floor on which it was deposited.

The appended list of the more common fossils of the Amsterdam we owe to the courtesy of Dr E. O. Ulrich:

<i>Solenopora compacta</i>	<i>Columnaria halli</i>
<i>Stictoporella cribrosa</i>	<i>Strophomena trentonensis</i>
<i>Rhinidictya mutabilis</i>	<i>Dalmanella rogata</i>
<i>Phyllodictya varia</i>	<i>Dinorthis pectinella</i>
<i>Eridotrypa minor</i>	<i>Bathyurus spiniger</i>
<i>Arthroclema pulchellum?</i>	<i>Leperditia n. sp.</i>
<i>Pachydictya acuta</i> var.	

GLENS FALLS (BASAL TRENTON) LIMESTONE

The zone of alternating shale and limestone, some 40 feet thick, which overlies the Amsterdam in the well sections and which is not exposed at the surface, is the only zone in the district to which the term Trenton limestone could at all properly be applied, and there is even question as to its propriety here since the shale exceeds the limestone. Outcrops on the Broadalbin quadrangle and in the eastern Mohawk valley, where the sections are exceedingly like those about Saratoga, leave little doubt that this zone is of lower Trenton age. On the Broadalbin quadrangle Miller has mapped this zone with the Amsterdam, and separate from the overlying Canajoharie shale. The Canajoharie shale, however, is of Trenton age, and it seems to us more fitting to group the basal zone which contains the thin limestone bands with this, as its basal portion, rather than with the Amsterdam, which we regard as of Black

River age. Ruedemann has termed this limestone the *Glens Falls limestone*, since its fauna has shown it to lie below beds of the Trenton Falls section.¹

THE CANAJOHARIE SHALE

BY R. RUEDEMANN

The Canajoharie shale is the surface rock in the southernmost area of the Saratoga quadrangle and thence extends northeast, occupying the area between the Snake Hill formation of the eastern trough and the McGregor fault and its branches. West of Saratoga it rests directly on the basal or Glens Falls limestone and southward the formation strikes toward the Mohawk river near which it passes under the Schenectady beds. Northward from the Schuylerville quadrangle it has not been traced beyond Glens Falls, the constituent divisions of the shale belt north of the Hudson valley having not yet been differentiated.

This formation, which is most typically developed in the Mohawk valley, has been fully described by the writer in Bulletin 162. It consists almost entirely of soft black, carbonaceous, more or less calcareous, argillaceous shales and is therefore quite distinct in its lithologic characters from the Normanskill-Snake Hill group, although where it has become involved in the folding, as in Albany county, it may through cleavage and slickensided slip planes become quite similar to some of the darker shales of the latter formations. It lacks, however, the smooth, lighter colored, gray, greenish and bluish purely argillaceous shales so prevalent in them, and the black Canajoharie shale weathers a characteristic light drab, like the Utica shale, while the dark shales of the Normanskill-Snake Hill weather grayish brown or spotted or whitish when somewhat siliceous. Nor does the Canajoharie contain any trace of the white weathering chert beds and grit of the shales of the eastern trough. A sandstone bed 2 to 3 feet thick was observed in only one case in the Snook kill below Gansevoort, although thinner layers of somewhat sandy shale are sometimes met with. On the other hand there frequently occur harder, bluish gray mud beds indurated by calcite which are mostly 3 to 6 inches but sometimes 3 to 4 feet thick, as in the bank of the Kayaderoseras creek above Ballston Spa. These mud beds break conchoidal or lumpy and are very fine grained. The shale is fissile and splintery

¹ N. Y. State Mus. Bul. 162, p. 22.

for the most part. Its uniform, carbonaceous, fine grained character is the most distinguishing feature of the formation.

Much of the shale contains pyrite which, becoming oxydized, fills the cleavage and bedding planes in some places with rusty brown films and produces efflorescences of alum salts on the protected walls of cliffs, as about Ballston Spa, and is probably also responsible for the occurrence of sulphuretted hydrogen in some of the springs. In some cases the graptolites were found very well preserved in pyrite.

These shales are flat on the two quadrangles here described, and are not involved in the intensive folding and overthrusting that has affected the Georgian, Normanskill and Snake Hill beds, although they may dip steeply near the fault planes. Owing to their uniform softness and flat position, they have not only been very deeply eroded but also fail to form ridges of folded harder beds, as the other shale formations of the region do. Outcrops are therefore extremely scarce in the entire belt, occurring only where the creeks have accidentally reached a higher part of the shale surface, that for the most part is deeply buried under drift. Since practically every outcrop of this shale is fossiliferous, most outcrops are marked on the map as fossil localities.

On the Saratoga quadrangle the most important outcrops are about Ballston Spa where the Kayaderoseras flows between cliffs of this shale 100 feet high. A few small outcrops sufficient to demonstrate the areal extent of the formation were observed in the bed of the Glowegee and its branches, in the southwest corner of the Saratoga map, and another in the creek bed at the Geyser and Carlsbad springs 2 miles southwest of Saratoga Springs. Thence northeastward all rock is hopelessly buried under sand until the Snook kill is reached, which in its upper branches exposes shale cliffs at the foot of Mt McGregor and falls and flows over Canajoharie rock for several miles north of Gansevoort. It again reaches bedrock about 4 miles above the mouth of the creek.

The *thickness* of this formation could not be determined in the area here mapped from the facts at hand. We know, however, that not more than 15 miles to the southwest it is not less than 1100 feet and there is no reason why it should originally have greatly diminished toward Saratoga county, this direction lying in line with the probable axis of the trough in which deposition took place. Since, however, the shale in this region was earlier uncovered by erosion than the belt at the foot of the Helderberg escarpment, it

probably has suffered a longer erosion and may for that reason be now much reduced in thickness.

The fauna of these shales on the two quadrangles is small but present in all outcrops and characteristic of the formation. It consists of the graptolites:

Corynoides calicularis *Nicholson*

Dicranograptus nicholsoni *Hopkinson*

Diplograptus amplexicaulis *Hall*

D. (Mesograptus) putillus *Hall*

D. (Mesograptus) mohawkensis *Rued.*

Climacograptus spiniferus *Rued.*

Glossograptus quadrimucronatus *mut. cornutus* *Rued.* and other mutations

Lasiograptus eucharis (*Hall*)

Besides these there are met with worms (*Eopolychaetus albanensis* and *Pontobdellopsis cometa*) described from this formation by the writer in Bulletin 42 (1901) and small brachiopods (*Leptobolus insignis* *Hall*, *Schizocrania filosa* *Hall*) and a few cephalopods (*Trocholites ammonius* *Conrad*, *Orthoceras arcuolineatum* *Rued.*, *O. hudsonicum* *Rued.*) and rarely a head of a *Triarthrus becki*. Of these are common only *Corynoides calicularis*, *Climacograptus spiniferus*, *Diplograptus amplexicaulis*, *putillus*, *mohawkensis* and *Lasiograptus eucharis*. *Dicranograptus nicholsoni*, so common in the Snake Hill beds, is very rare, while *Lasiograptus eucharis* is present in every outcrop; the other graptolites here cited are not always associated but rather distributed in subzones of the formation not yet distinguished. Thus in Ballston Spa the beds exposed in the village are full of *Climacograptus spiniferus* and *Diplograptus amplexicaulis*, but going up the Kayaderosseras creek one first meets thick-bedded mud shales and above these *Glossograptus quadrimucronatus* *mut.* and *Lasiograptus eucharis* have become the dominant forms. The outcrop at the Carlsbad Spring near Saratoga contains:

Diplograptus (Mesograptus) mohawkensis

Climacograptus spiniferus, and

Lasiograptus eucharis

As a rule, one meets only *Corynoides calicularis* and *Lasiograptus eucharis*, the two most common fossils, as at the Glowegee and the upper branches of the Snook kill. At the Gansevoort fall, however, also *Glossograptus quadrimucronatus* mut. *cornutus*, a characteristic form of an upper horizon of the Canajoharie shale was obtained in typical specimens.

Correlation. We have shown in another paper,¹ that the Canajoharie is of lower Trenton age and essentially contemporaneous with the Snake Hill shale. The two have, therefore, some important horizon markers, especially graptolites, in common. While, however, the Snake Hill shale rests on either upper Normanskill shale or Rysedorph Hill conglomerate and belongs to a vertical series that begins with the Georgian beds at the bottom, the Canajoharie shale can be seen to rest on the basal Trenton limestone at Glens Falls, the latter being underlain in turn by the Amsterdam limestone. It is therefore to be inferred that although the Canajoharie and Snake Hill shales may be approximately synchronous, they were formed in different basins and have come in contact through later diastrophic movements (see diagram and page 100.)

The Canajoharie shale is equivalent to the lower part of the Martinsburg shale in Pennsylvania and New Jersey, with which it has the characteristic fossils in common and is probably continuous with it through southern New York. The Martinsburg shale, however, comprises also beds of Utica and Eden age.

THE SCHENECTADY FORMATION

In the southwestern corner of the Saratoga sheet, from Birchtown westward, the grits of the Schenectady formation are exposed in a number of places, showing that this formation just reaches the sheet from the southwest.

The Schenectady formation consists in the lower Mohawk valley of 2000 feet of grits and sandstones with interbedded black and gray argillaceous shales, the two forming a monotonous, uniformly alternating series throughout this great thickness. The sandstone beds are quarried about Schenectady and Aqueduct, and in the latter place, where the Mohawk river in its new postglacial course breaks through a ridge of these harder beds, an excellent section of a portion of the formation is furnished. These gray, impure sandstones and gray to black argillaceous shales have, until recently,

¹ N. Y. State Mus. Bul. 162, p. 29.

been currently correlated with the "Hudson River," Lorraine or Frankfort formations, mainly for the reason that they overlie the black (Canajoharie) shales, which were identified with the Utica shale; further because they are lithologically like the Lorraine beds; and, finally, because they seem to be continuous westward with the Frankfort shale, the lower division of the Lorraine group as it was hitherto understood. Recent investigations by the writer¹ have, however, shown that this thick formation contains a fauna not younger than Trenton, that the underlying black shale is not Utica but early Trenton in age, and that these sandstones and shales are only apparently continuous with the Frankfort of the Mohawk, the Frankfort pinching out gradually eastward and the Schenectady beds rapidly thinning out westward. The Schenectady formation is therefore now considered as of middle and upper Trenton age.

The life of this formation has proved to be an extremely peculiar one. It consists of a few graptolites, brachiopods, cephalopods, lamellibranchs, trilobites and ostracods of upper Trenton aspect, with prenuncial Utica forms, but besides there occurs, in certain layers, a profuse mass of fragments of new eurypterids and seaweeds (*Sphenophycus latifolius*). Ten species of eurypterids, belonging to various genera, have so far been recognized, but it is obvious from fragments of sculptured pieces of integument that the fauna was still greater. The seaweeds, the rapid alternations of shales and sandstones and the mud cracks indicate that the great thickness of beds was deposited in shallow water, and the uniformity of the formation shows that this water kept deepening approximately proportional to the accumulation of the sediments. The formation extends mainly from southwest to northeast in a trough that is here termed the lower Mohawk or western trough.

While at present the formation reaches only the southwestern corner of the Saratoga quadrangle, its great thickness on the adjoining Schenectady quadrangle, and the fact that the strike of the formation is in the direction of this sheet, leave no doubt that it once extended much farther north, probably across the sheet, and has since been eroded away.

The edge of the formation forms now a low escarpment, shown by the contour lines in the very southwest corner of the sheet, and this, like the typical Helderberg escarpment, farther south, is clear evidence of the former extension farther northward of the formation.

¹ *Op. cit.*, p. 50.

In front of this low escarpment, at several places along the road leading due north to the Glowegee, small outcrops of dark shales were observed, the shale being sandy in some parts and fissile and argillaceous in others, but nowhere of the character of the Canajoharie shale. This shale we have mapped with the Schenectady beds.¹

The Indian Ladder beds. The Schenectady beds are overlain in the Helderberg escarpment at the Indian Ladder by a similar formation, 300 feet or more in thickness, that has furnished a faunule hitherto known only from the Eden beds about Cincinnati and of an age roughly corresponding to that of the Frankfort beds in central New York. This formation, which is of small east-west extension, was deposited after an emergence in Utica time in the narrow southern extension of the western trough. The submersion, however, proceeded probably from the south, and it is very probable that it extended over the Saratoga sheet, although no rocks of this period are left there.

STRUCTURAL GEOLOGY OF THE WESTERN BASIN

BY H. P. CUSHING

General statement. The Paleozoic rocks of the western basin have been deformed chiefly by faulting, which has equally affected the Precambrian rocks. Folds are not prominent and the rocks show but gentle dips, except locally near faults. The district shows little sign of lateral compression and the faults all appear to be normal. In these two respects arises the chief structural difference between the rocks of the western and eastern basins.

Vanuxem, years ago, described the normal faults which cross the Mohawk valley, from Little Falls to Hoffmans Ferry.² The next geologist to consider them in any detail was Darton, who studied and mapped all the Mohawk faults, especially extending the work north of the river, and also carrying it northeastward to include the Saratoga region.³ This was a most excellent piece of work and has formed the basis for all subsequent investigation of these faults.

¹ Professor Miller has, on the adjoining (Broadalbin) quadrangle, mapped the sandstone-shale alternations of the Schenectady formation as Frankfort beds, and the underlying shale of the same formation, as Utica, the Schenectady beds having at that time not yet been studied by the writer and separated from the Frankfort shale.

² *Geology*, 3d Dist., p. 203-II.

³ *N. Y. State Geol. 14th Ann. Rep't*, 1894, p. 33-53.

Still more recent work on some of the faults which reach the Saratoga quadrangle has been done by Prosser, Cumings and Fisher in their mapping of the Hoffmans Ferry fault across the Amsterdam quadrangle, near the north edge of which it gives rise to two branches; and by Miller in his mapping of these and other faults of the Broadalbin quadrangle.¹ Of these only the Hoffmans Ferry fault and branches pass over on the Saratoga quadrangle, while other and more easterly faults come in.

All the larger of these Mohawk faults have a trend somewhat to the east of north, and a rude parallelism with one another. To the south they all run into the great thickness of upper Ordovician shales, and as soon as these come to form the surface rocks on both sides of the fault, it is exceedingly difficult to trace the dislocation farther. We do not as yet know whether they die out in the shales or not. To the north the faults run into the Precambrian rocks; and so soon as they have these on both sides of the fault, a similar difficulty arises in the effort to trace them farther. But they seem to run entirely across the Adirondack region from south to north and diminish in frequency toward the west. Hence it results that they abound in the southeast border of the region and are practically absent on the northwest. With their parallelism they divide the region into a great series of rock slices or segments which have shifted up and down past one another and broken the continuity of the rock formations.

The fault planes are seldom visible but such evidence as we have indicates that they are nearly vertical breaks and are all of the type known as normal faults. In the great majority of them the east side has dropped in level relatively to the west side, but in a few of them the reverse is true.

In addition to the relative displacements of the adjacent slices along the fault planes, the upper surfaces of the slices have usually received a tilt toward the west, each slice thus constituting the upthrow side of a fault along its east edge, and the downthrow side of the next fault along its west edge, as illustrated in figure 4.

The faults. Two of the great faults of the Mohawk region, the Hoffmans Ferry (much better abbreviated to Hoffmans) and the McGregor fault, the latter here named for the first time, cross the Saratoga quadrangle. The remaining faults mapped are branches of these two great breaks.

¹ N. Y. State Mus. Bul. 34 and map; Bul. 153 and map.

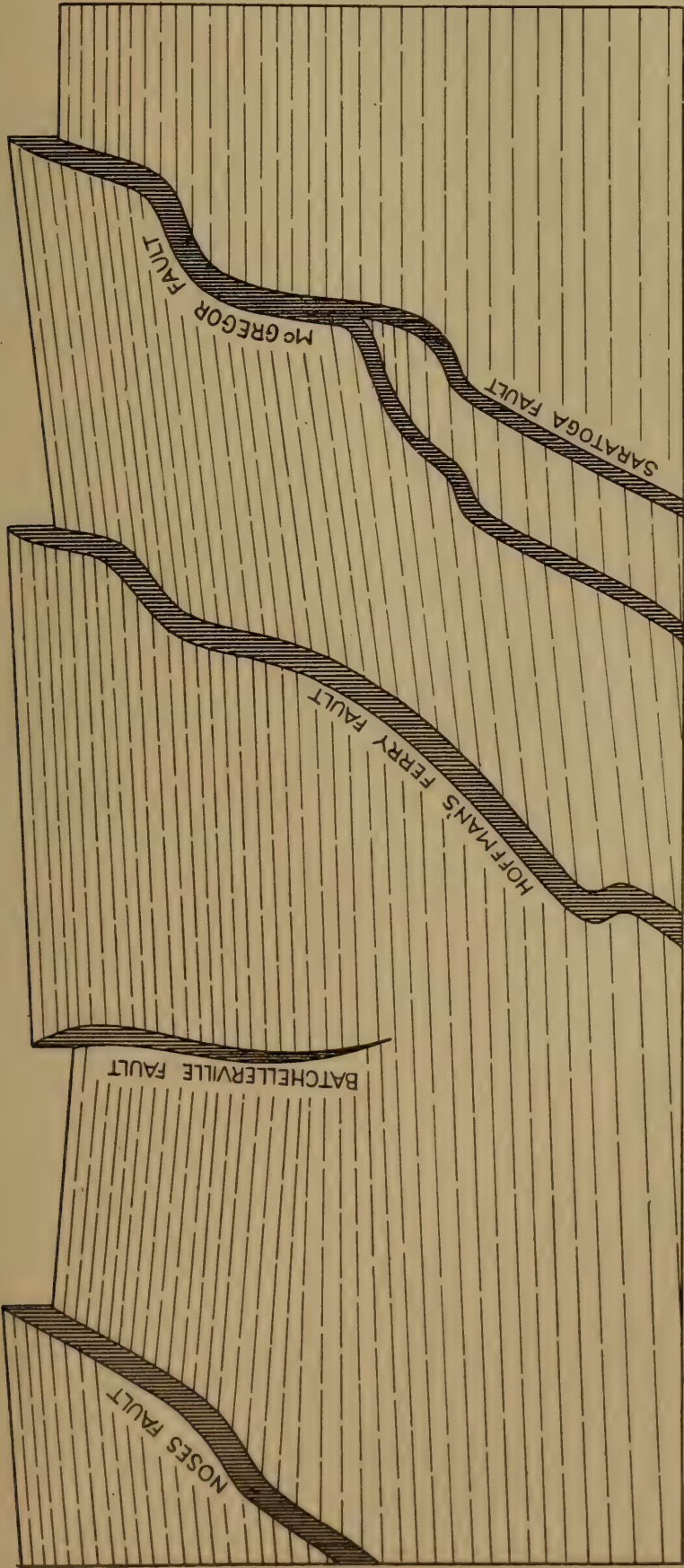


Fig. 4 Diagram of the four principal faults of the Saratoga and Broadalbin quadrangles to illustrate the manner in which they longitudinally slice the country. Minor faults and branch faults are omitted. The Batchellerville fault also is not a member of the principal group but a subsidiary break in the block between the Noses and Hoffmans Ferry faults. Vertical scale greatly exaggerated.

The Hoffmans fault enters the Saratoga quadrangle on its west margin 1 mile northwest of East Galway and, pursuing a general north-northeast course passes on to the Luzerne sheet a mile west of Corinth. At Hoffmans Ferry on the Mohawk (Amsterdam quadrangle) the displacement is estimated by Cumings at 1300 feet and by Prosser at 1600 feet.¹ Near the north edge of the Amsterdam quadrangle the fault sends off two branches to the east, each of which takes part of the throw of the main fault. These two branches, called by Miller the West Galway and East Galway faults, continue across the Broadalbin quadrangle on to Saratoga. Across Broadalbin, Miller estimates the throw of the Hoffman fault as but 250 feet, but states that this rapidly increases in its course across the Saratoga quadrangle.²

The scarp of the Hoffmans fault is the most prominent topographic feature of the Saratoga region, though nearly equalled by the McGregor scarp. The summit knobs of the range reach elevations of over 2000 feet, towering as the west wall of the Kaya-derosseras valley, the valley floor not greatly exceeding 600 feet altitude. None but Precambrian rocks occur west of the fault within the quadrangle; but east of it such heavy drift is banked up against the face of the fault scarp all the way from East Galway to near South Corinth that no rock exposures are seen. About South Corinth Precambrian rocks are at the surface east of the fault; about East Galway rocks of the Theresa formation are at the surface. What lies between the two is chiefly conjectural. But the rapid increase in prominence of the fault scarp in passing north from East Galway can, in this instance, be due to nothing except increasing throw. The surface of the western block is tipped to the south more than that of the eastern block. Back from Corinth therefore the throw is equal to the height of the fault scarp plus an unknown amount; hence Miller's estimate of 1000 feet is modest, and the throw is likely 500 feet in excess of that.

To recapitulate: the great throw of the Hoffmans fault at Hoffmans Ferry is split into three parts by the branching of the fault so that, across the Broadalbin quadrangle, the main fault retains only

¹ In vertical faults in nearly horizontal rocks, such as these, the displacement is practically all throw, so far as can be told. At Hoffmans Ferry the surface beds on the western, or upthrow, side of the fault are buried under a thickness of from 1300 to 1600 feet of younger rocks on the opposite side, according to these estimates. Relatively to the beds on the western side the corresponding ones on the east have been vertically dropped by that amount.

² N. Y. State Mus. Bul. 153, p. 46.

a small fraction of its original throw, the remainder being taken up apparently by the branch faults (West and East Galway faults). Across the Saratoga quadrangle the main fault rapidly regains its original amount of throw. This would naturally suggest a loss of throw in the case of the two branch faults, and such meager evidence as we have in regard to them is corroborative of this suggestion.

West Galway fault. The West and East Galway faults enter the Saratoga quadrangle near its southwestern corner and not greatly over half a mile apart. They are easily traced for 3 or 4 miles when they run into heavily drift-covered territory in which their course, and even their existence, is quite uncertain. Where outcrops reappear, in the northern portion of the quadrangle, two faults are found which are on the trend of these two, and they are assumed to be their prolongations; but the uncertainty of this must be emphasized. If the assumption is correct, interesting consequences follow.

South of East Galway the ravine that runs across the West Galway fault, and which cuts down into the Precambric just west of the fault line (see areal map), gives the data for an approximate estimate of the fault's throw at that point. The Precambric is on one side, the upper portion of the Theresa formation on the other, so that the throw is just about equivalent to the combined thicknesses of the Potsdam and Theresa formations, or from 250 to 300 feet.

Near this point, one and one-half miles south of East Galway, there is a dropped wedge of rock, or horse, along the West Galway fault, which is interesting because the rock concerned is much younger than on either side of the fault. Potsdam sandstone adjoins it on the west or upthrow side of the fault, and the upper beds of the Theresa formation on the other side, the downthrow. The rock of the included wedge is upper Little Falls and basal Amsterdam, hence higher in the section than the Theresa on the downthrow side by the full thickness of the Little Falls dolomite, at least 300 feet. Figure 5 shows a plan of the outcrops and our interpretation of the relations.

The wedge of Little Falls and Amsterdam shows abundant outcrops. At the north end of the wedge and apparently on the



FIG. 5 Plan of outcrops on the West Galway fault, showing the wedge with Little Falls dolomite at the north and Amsterdam limestone at the south, with two additional outcrops, no. 1 of Theresa beds and no. 2 of Potsdam sandstone.

Scale 1 inch = 350 yards.

east side of the fault, at a slightly lower level than the nearby Little Falls, is an outcrop of the Theresa passage beds; at the south end, and unquestionably on the west side of the fault, Potsdam sandstone outcrops. Farther west outcrops are plentiful on the west side of the fault but there are none on the east side. The uncertainty in regard to the matter is whether the Theresa is really on the east side of the fault; a slight swinging of the northern apex of the wedge toward the right would put it on the west side. The uncertainty is regrettable; we can only say that everything we saw in the field led to the confident belief in the relations as illustrated, and had not the Theresa exposure been forthcoming we should have been forced to map it at that point owing to the testimony of exposures a mile to the southwest. Nevertheless the drift is very heavy and the mapping of a much faulted district such as this must needs be very uncertain under the circumstances.

Rock horses caught in along faults are common enough. But the rock concerned is usually intermediate in age between the rock of the upthrow and downthrow sides; it has dropped relatively to the upthrow side but has not dropped so far as has the downthrow side. Such a wedge occurs in Saratoga along the Saratoga fault. But in the case under consideration we have a small block about 350 yards in length, which has dropped down along the fault zone some 300 feet more than the downthrow side has dropped. It is a diminutive example of a trough fault. It is difficult to conceive of the mechanical conditions which would permit so small a block to drop so deeply into the jaws of a fault. It may be the apex of a large dropped block, otherwise entirely eroded away.

What seems to be another and similar case is found along the Hoffmans fault a mile west of Porter Corners where a small block of Little Falls dolomite lies in the fault zone closely adjacent to the Precambrian exposures to the west of the fault. To the east the drift covers everything, but unless our attempted mapping is totally at fault, the rock on the downthrow side should be the Potsdam sandstone. Certainly Precambrian rocks come in on the east side of the fault 2 miles away to the northeast. So we infer this to be a small dropped block of the same type.

As has been said, the mapping of the West Galway fault across the quadrangle is highly conjectural. There should be a fault between the Precambrian exposures south of South Corinth and those of the Theresa at North Greenfield; there should be a fault just west of the Potsdam exposures at Corinth, cutting them off.



Rock City falls over Calciferous sandstone; student standing on its top with Trenton above.

These are on the same line with one another and also about on line with the prolongation of the West Galway fault. The throw also is much the same so far as can be judged, but the direct evidence is meager.

East Galway fault. The evidence for the extension of this fault as far as Middlegrove is fairly satisfactory. At first it shows Canajoharie shales on the downthrow side. Back from Rock City Falls the Amsterdam and the Little Falls come in. On the upthrow side the horizon varies but little, the surface of the slice lying very flat. Beyond Middlegrove it runs into the heavy drift, but its trend would be with the axis of the preglacial valley for the next few miles. Farther north its occurrence is problematical, but the presence of a fault is needed to explain the occurrence of the Potsdam and Theresa formations at and south of Corinth, which are wholly out of adjustment with the same formations in the eastern part of Greenfield township. We think a fault must lie here, and it seems more reasonable to connect it with the East Galway fault than to assume a wholly separate break. The chief objection to this view is that the fault south of Corinth downthrows to the west, while at East Galway the downthrow is to the east. This may be explained, however, by the fact that the slice of territory to the west of the fault lies very flat, while to the east of the fault the rocks are more tipped, having a very noticeable southwest dip. Because of this the throw steadily diminishes in passing north as far as a point southeast of Porter Corners, where the Theresa formation is present on both sides of the fault and the throw has become zero. To the northward the throw reverses and the older rocks are present on the east side of the fault instead of on the west. Faults of this type, called "rotatory" faults, are not very common, which is the cause for greater regret, as the heavy drift-covering makes the whole matter so uncertain.

Rock City Falls fault. The small fault at Rock City Falls has been described by both Darton and Prosser. It is well exposed in the creek, the fall itself being practically on the fault line, 15 feet of Little Falls dolomite underlying the Amsterdam on the west or upthrow side, while the base of the Amsterdam is below the creek level on the downthrow side. To the south of the creek also recent quarrying of the Amsterdam has exposed the fault line excellently for a short distance, though with Amsterdam limestone on both sides, a little fault breccia, and with much updrag of the rock on the downthrow side. The throw of the fault is only 25 to 30 feet.

Southward it runs into shales and can not be traced. Northward there are indications of it for a mile, beyond which it is hidden by drift.

McGregor fault. Darton spoke of the group of faults about Saratoga as the Saratoga faults. The group seems to us to consist of a main fault with branches and we desire to retain the name Saratoga fault for the branch in the village, often called the "Springs" fault. The grand scarp of the main fault along the front of Mt McGregor has suggested that as a most fitting name for this fault.

In front of Mt McGregor the fault has Precambrian rocks on the upthrow side and Canajoharie shale on the downthrow, so that the full thickness of the Potsdam, Theresa, Hoyt, Little Falls and Amsterdam formations is faulted out. This means a minimum thickness of at least 600 feet; in addition there is another thickness of 600 feet of Precambrian in the fault scarp, with the summit likely 200 feet below the horizon of the base of the Potsdam. How much thickness of the Canajoharie shale is involved is uncertain, but the throw of the fault is certainly 1400 feet at Mt McGregor, and likely 200 feet more than that. It seems to be increasing toward the north.

Near Kings Station, 4 miles north of Saratoga, a branch fault sets off from the main fault toward the northeast, bringing a block of Little Falls dolomite to the surface between the shales and the Precambrian. This may be called the Gurnspring fault. Carbonated waters rise along it in the same way and under very similar structural conditions as they do along the Saratoga fault. This block of dolomite seems cut off at the north by shales, and hence by another fault, but rock outcrops are so few that conditions are very conjectural.

To the northward the McGregor fault runs as one of the prominent breaks of the region, passing to Lake George and forming the prominent fault scarp along the west shore of the lake and of Northwest bay, at the apex of which it passes inland away from the lake.

Between Kings Station and St Clements the McGregor fault runs unbroken, but at the latter place, somewhat over a mile north of Saratoga, it sends off two branches, much diminishing the throw of the main fault. This swerves around to the west and becomes eventually lost under the heavy drift of the Kayaderosseras valley. Its throw is rapidly diminishing and it probably dies out in that district.

Woodlawn Park fault. The first of the two branches given off from the main fault at St Clements may be named from this park, as it runs through its northern portion. The only rock outcrop in this portion of the fault block is the Hoyt limestone exposure at the railroad quarry, closely adjacent to Precambrian on the north and to Little Falls dolomite on the west and south. Farther south abundant exposures of Little Falls dolomite and overlying Amsterdam limestone occur within the fault block, while across the fault to the southeast is drift-covered territory with Canajoharie shale for the surface rock. Then the fault runs into shales and is lost, as happens to all the faults of the region in like circumstance. The throw of this fault north of Saratoga is just about the thickness of the Little Falls dolomite in amount, hence 300 feet at least.

Saratoga fault. The second branch given off from the main fault at St Clements follows the strike of the main fault into Saratoga and the upthrow side is constituted of the platform of Little Falls dolomite on which the western half of the village is built. At the north edge of the village the strike of the fault swerves somewhat to the west and so continues to West Congress street and Broadway, where it swerves sharply to the west. This part of its course is covered by drift but the change in direction has been disclosed by excavations made for sewers, the data having been furnished by Mr S. J. Mott, the village engineer. By these means the fault has been traced in this direction for something like one-third of a mile, after which its course is largely conjectural.

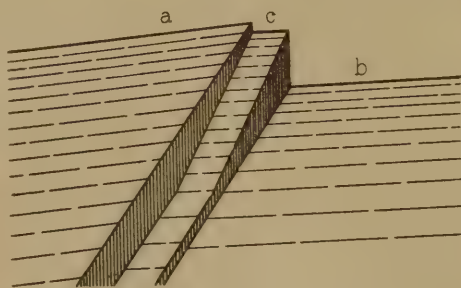


Fig. 6 Diagram of the Saratoga fault and the tipped wedge of Amsterdam limestone in the northern part of Saratoga Springs; a = upthrow side of Little Falls dolomite; b = downthrow side of Canajoharie shale; c = Amsterdam wedge; vertical scale and tilt of wedge surface exaggerated

The fault has long been known because of its close association with the older springs at Saratoga, but when compared with the other breaks of the region its notoriety is found to be out of all proportion to its magnitude. It is but a small break. In its course through the village there is everywhere associated with it a narrow wedge of Amsterdam limestone caught in along the fault zone. This is best seen back of the Star spring and thence northward for a few rods. The low fault scarp, 20 to 25 feet in height, shows the upper beds

of the Little Falls dolomite, and is today best shown back of the High Rock spring (plate 8). Small patches of basal Amsterdam lying in contact with the Little Falls somewhat farther north show that this is the very summit of the formation. At the Star spring a wedge of Amsterdam limestone appears lying closely against the fault face and with a tipped upper surface, rising toward the north, falling toward the south. Back of the Red spring it has risen to the full height of the fault scarp; at the High Rock spring it is some 15 feet below the surface of the ground. Figures 6 and 7 clearly show the disposition of this wedge of Amsterdam.

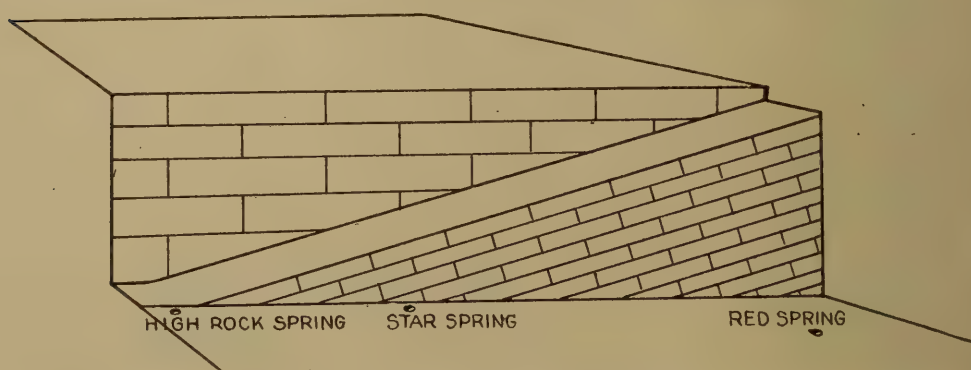


Fig. 7 Illustration of the manner in which the tipped block of Amsterdam limestone lies against the fault face, as seen in looking at the fault from the downthrow side; tilt of block much exaggerated; 1 = Red spring, 2 = Star spring, 3 = High Rock spring.

At the Star spring a drilled well gave 38 feet of drift and 62 feet of shale before reaching the summit of the Amsterdam limestone. This well is only a very few yards east of the Amsterdam wedge outcrop and the fault line, showing clearly that the wedge is but a very narrow block caught in along the fault. Ignoring it and estimating the throw of the Saratoga fault from the exposures and the well record at the Star spring, a result of about 160 feet is obtained, 100 feet of drift and shale, 40 feet of Amsterdam limestone and the 20 feet of Little Falls shown in the fault scarp.

The Amsterdam wedge seems to continue along the fault all the way through Saratoga between the two swerves in its course. This is indicated by the fact that it is the surface rock just east of the fault at the Hathorn spring, and also is the surface rock at the Congress spring, as shown by the drill core. It really amounts to a parallel fault lying very close to the main fault. South of the Congress spring its course is lost under heavy drift.

Hathorn spring record. The deep bore at the Hathorn spring went down 1006 feet. The driller reported 62 feet of drift at the top and 231 feet of Potsdam sandstone at the bottom, the drill resting in this formation. Amsterdam limestone was found directly under the drift. The Potsdam is so thick that it seems that the full thickness of the Theresa must also be included. If this be the case, the Hoyt, Little Falls, and Amsterdam have a combined thickness of 713 feet, whereas judging by such other evidence as we have of their thickness it should not exceed 450 to 500 feet. This suggests that the drill may have crossed a fault so as to go through a certain thickness of beds twice. This would be quite possible since the drilling started on the Amsterdam wedge and it is only necessary to assume that the branch of the fault east of the wedge fades toward the main fault in order to have just the necessary conditions, as illustrated in figure 8. The drill core is in existence but we have not had opportunity to study it. Such study should show whether any part of the section is duplicated in the record or not. If there is duplication the illustration probably furnishes the reason. If there is none, then the Little Falls dolomite and Hoyt limestone taken together are considerably thicker than we have supposed.

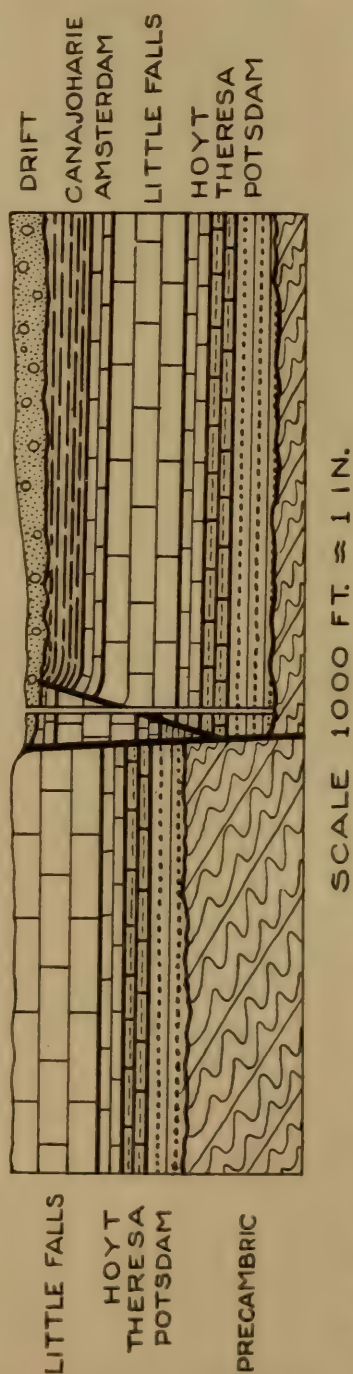


Fig. 8 Diagram to illustrate supposed underground conditions at the Hathorn spring, in explanation of the great thickness of Paleozoic rock shown in the well. Starting in the Amsterdam wedge the bore is thought to pass across the branch fault and repeat part of the section already passed through.

General remarks on the faults. The large faults of the Mohawk and eastern Adirondack regions show a frequent tendency

to curve from the north to the northeast and from the northeast back to the north. It has been shown that there are principal joint sets in both these directions in the region and the fault slips are thought to be determined in position by these joints. The average trend of the faults is to the north-northeast. In this direction there are no main joints. The faults maintain this general direction by alternately following the north and the northeast joints, this apparently being a more easy method of accomplishing the deformation with north-northeast trend than the method of creating new fractures in that direction along which the slipping might take place. Both the Hoffmans and the McGregor faults illustrate this curving tendency.

The faults send off frequent branches, which are more likely to appear at a curve. In many cases one branch will be found in a north-south and the other in a northeast-southwest direction. By the branching, the throw of the fault is divided among the branches. It often happens that the throw of the branches steadily diminishes until they fade out while at the same time that of the main fault increases until it attains the amount it had prior to the branching. This process seems frequently repeated.

During the successive stages of the faulting in the region, as the long rock slices slipped past one another, it is but natural that irregularities in the slipping would develop, producing cross strains in the slices and tending to promote cross breaks. That such cross breaks are of frequent occurrence in the general region is quite certain, though exposures are not sufficiently good to permit their certain location within the Saratoga quadrangle. The obvious tendency would be for such cross breaks to occur along planes of weakness, such as the contacts between two formations of very different strength. There seem to be two zones in which such breaks would be most apt to occur, one at the contact between the Precambrian crystallines and the Potsdam sandstone, and the other at the contact between the limestones and the overlying shales.

There is some suggestion of frequent cross breaks in the faulted slices at the Precambrian-Potsdam contacts, but in no case known to us has the evidence been worked out in detail. A prominent topographic feature of the southeast border of the Adirondacks is the way in which the Precambrian portions of the fault slices sharply break down on the south to the level of the Paleozoic plain. In every one of the faulted slices the Precambrian rocks are followed by Paleozoic rocks on the south. The Precambrian territory

is commonly elevated territory, the Paleozoic contrastingly at low altitude. The abrupt way in which such Precambrian ridges as those of French and Putnam mountains, and of Sugar Loaf, on the Glens Falls quadrangle, break off at the south, with an abrupt drop in level of from 500 to 800 feet, would seem of necessity to imply cross faulting in the fault slices concerned.

On the Saratoga quadrangle the evidence for cross breaks at the contact between the Amsterdam limestone and the overlying Canajoharie shale seems quite conclusive. The Amsterdam dips to the south are always higher than those of the Little Falls dolomite, showing downfolding or downdragging in that direction, and in the shales the dips are even higher for a time, so that even close to the Amsterdam border the thickness of shale over the limestone is considerable. Exposures do not suffice to determine whether we are dealing with monoclinical folding or with faulting; but since the former could be considered merely an initial phase of the latter, either one would indicate the horizon as a likely one for cross breaks.

Joints. Our readings on joint directions on the Saratoga quadrangle are not sufficiently numerous to make it worth while to plot them. The Precambrian rocks cover but a small portion of the quadrangle. They are as usual much jointed nearly everywhere and appear to be referable to four sets, a north-south, an east-west, a northeast and a northwest set. But they do not hold their direction true, curving through considerable arcs. In the Grenville strike joints are prominent, in this case the east-west set. Of the vertical joints the northeast set is the most prominent, the north and the northwest less so and more irregular. The Paleozoic rocks are not very sharply jointed in the main, and the joint directions are very irregular.

PALEOZOIC ROCKS OF THE EASTERN TROUGH

BY R. RUEDEMANN

All the sedimentary formations of the eastern trough in the Saratoga and Schuylerville quadrangles belong to the Cambric and Ordovician (Lower Siluric) systems. The following stratigraphic units have been distinguished:

Table of formations exposed

Ordovician	Trenton	{	9 Snake Hill shale
		{	8 Upper Normanskill shale with Rysedorph Hill conglomerate
	Chazy	{	7 Normanskill shale <i>s. str.</i>
		{	6 Bald Mountain limestone
	Beekmantown	{	5 Deep Kill shale (possibly present)
		{	4 Schaghticoke shale
Cambrian	Georgian or Taconic	{	3 Schodack shales and limestones
		{	2 Eddy Hill grit
		{	1 Bomoseen grit

The Cambrian system is represented only by its lowest group, the Georgian. The Georgian rocks are found only along the eastern edge of the Schuylerville sheet, whence they extend eastward over the Greenwich and Rensselaer plateaus. The discovery and demonstration of the presence of Lower Cambrian rocks, now known as Georgian, may be said to have taken place right at this eastern edge, for it was from the neighborhood of Bald mountain that Dr Ebenezer Emmons obtained the fossils *Elliptoccephalus asaphoides* and *Atops trilineatus* which demonstrated, in that well-known controversy on the Cambrian system in America (Emmons's Taconic), the presence of rocks as old as the Primordial stage of Barrande in the slate belt of eastern New York. Through the investigations of Ford, and especially those of Walcott and Dale, the faunas and rock types of the Georgian have become well known. Walcott¹ first clearly separated the Georgian and Ordovician terranes, and Dale²

¹ The Taconic System of Emmons. Amer. Jour. Science, 1888, 35:229, 307.

² Dale, T. Nelson. New York-Vermont Slate Belt. U. S. Geol. Surv. 19th Ann. Rep't, 1893, p. 153.

established the succession of the subdivisions of the Georgian with such accuracy as the great difficulties arising from the extremely disturbed condition of the beds will permit. He distinguishes, in ascending order (see chart facing page 178, *op. cit.*):

A *Olive grit*. Olive green grit (graywacke), more or less massive, spangled with minute scales of hematite or graphite, sometimes with small quartzite beds, frequently calcareous, generally weathering a pale brick red. Associated with it in places a bed of quartzite 12 to 55 feet thick, 50 to 200 feet.

B *Cambric roofing slates*. Roofing slate, grayish green, purple or mixed green and purple, alternating with beds of calcareous quartzite up to 5 feet and limestone breccia up to 40 feet thick. Fauna: *Olenellus*; *Microdiscus lobatus*, *M. speciosus*; *M. connexus*; *Solenopleura*, possibly *nana*; *Obolella*; *Iphidea pannula*; *Hyolithes communis*; *Hyolithellus micans*; trails of annelids. 200 to 240 feet.

C *Black patch grit*. Dark gray grit or sandstone with black shaly patches, sometimes with calcareous nodules. *Olenellus* in both grit and calcareous nodules. 10 to 40 feet.

D *Cambric black shale*. Black shale or slate, generally weathering blue black, sometimes pyritiferous, with thin beds of limestone and less frequently limestone breccia. Fauna: *Linnarsonia sagittalis* var. *taconica*; *Orthis*, probably *salemensis*; *Lingula*?; *Lingulella coelata*?; *Lingulella granvillensis*; *Hyolithes communis*; *Leperditia dermatodea*; *Conocoryphe*—sp.?; *Solenopleura*, probably *tumida*; a phyllocarid crustacean, closely related to *Ceratiocaris*; spicules of *Protospongia*; also *Microdiscus speciosus*; *M. lobatus* and *Iphidea pannula*. 50 to 250 feet.

E *Ferruginous quartzite and sandstone*. Quartzite, usually with spots of limonite; in places, however, a bluish calcareous sandstone (grains of quartz with a calcareous and ferruginous cement). 25 to 100 feet.

Professor Dale found 335 to 1400 feet of Lower Cambric rocks exposed but since the thickness of the basal member, the olive grit, is not known, the thickness may easily exceed the maximum. The upper divisions, C, D and E, are described as intermittent and B as often wanting in the western part.

In a later paper Dale¹ has arranged the Georgian beds of the region adjoining south of the one here discussed, somewhat differently. He there constructs the following table of formations:

¹ Dale, T. Nelson. Geology of the Hudson Valley between the Hoosic and the Kinderhook. U. S. Geol. Surv. Bul. 242, 1904, p. 29.

Table showing the Lower Cambrian series as exposed in Rensselaer county and part of Columbia county, N. Y.

SERIAL LETTER	DESCRIPTION OF STRATA	FAUNA	ESTIMATED THICKNESS IN FEET
J	Greenish shale . . . . .	.....	50
I	Thin-bedded limestone, or dolomitic limestone, in varying alternations with black or greenish shale and calcareous quartz sandstone. Some of the limestone beds brecciated within the sandstone or shale and forming brecciation pebbles, in places, however, beach pebbles	Olenellus fauna	^a 20-200
H	Greenish, reddish, purplish shale, in places with small beds of more or less calcareous quartzite. At Troy, in upper part a 2½ foot bed of calcareous sandstone	Oldhamia, annelid trails Hyalolithes and Hyolithellus	25?-100+
G	Granular quartzite, in places a calcareous sandstone	.....	10-40
F	Olive grit, metamorphic, usually weathering reddish; absent at south	Traces of?	18-50
E	Greenish, or reddish and greenish, shale with small quartzite or grit beds	Casts of impressions, Oldhamia ^b	65-535
D	Massive greenish quartzite, in places very coarse	.....	10-50
C	Reddish and greenish shale with small beds of quartzite or grit (rarely up to 5 feet thick)	Casts of impressions, Oldhamia	30-80
B	Massive greenish quartzite, in places very coarse	.....	8-40
A	Reddish and greenish shale with small beds of quartzite or grit, from 1 to 12 and, rarely, 24 inches thick	Casts of impressions, Oldhamia	50-80

^a Usually 50. ^b Oldhamia occurs in A, C, or E, and quite possibly in all three.

Minimum, 286. Maximum, 1225 +

A comparison of the two series of divisions, that for the slate belt of Washington county and Vermont and that for Rensselaer county, furnished by Dale, shows that the olive grit in the first is overlain by a great mass of colored slate, the "Cambric roofing slates," and in the latter rests on a still greater mass of colored shales; further that the Cambric roofing slates and the Black patch grit are absent in the latter series, where a granular quartzite 10 to 40 feet thick and a second mass of colored shales 25? to 100+ feet thick intervene between the olive grit and the black shale and thin-bedded limestone. In Washington county this is followed by another quartz mass, the ferruginous quartzite, and in Rensselaer county by greenish shale.

In accordance with the present practice to name the units after their type localities instead of their lithologic and faunistic characteristics and to avoid confusion between the different horizons of colored shales and quartzites, we propose here the following names for these units:

1 *Bomoseen grit* (olive grit). Olive green grit, nearly a pale brick-red. Associated with it in places a bed of quartzite 12 to 55 feet thick. 50 to 200 feet. The type locality of this unit is, according to Dale, on the west side of Lake Bomoseen, Vt., "one-quarter of a mile west of the road running north from Hydeville, on the north side of road to Fairhaven." It is finely exposed about Greenwich, N. Y., especially in ridges northwest of that town, and south on Louse hill, but disappears in Rensselaer county where it still outcrops east and southeast of Troy.

2 *Mettawee slate* (Cambric roofing slate Dale). See definition, page 67. These slates extend typically from Pawlet, Vt., and Granville, N. Y., to Fairhaven, Vt. The town of Granville, which is the center of the industry, would furnish a good name if it were not preoccupied. We have therefore taken the name of the Mettawee river which drains the region.

3 *Eddy Hill grit* (Black patch grit). This formation, which is defined on page 67, is termed from Eddy Hill, near Fairhaven, Vt., where it is seen to rest on the Mettawee slate, and carries fragments of the *Olenellus* fauna. Its extension southward is not safely established on account of its great similarity to the "Hudson" grit.

4 *Schodack shales and limestones* (Cambric black shale). Defined on page 67. This formation of black shales and limestones always occurs near the top of the Georgian; it is well

exposed in many localities, as on Bald mountain near Greenwich, about Granville, etc. The name is taken from the fine exposures two miles south of Schodack Landing, N. Y., on the bank of the Hudson river and the belt of these rocks in the town of Schodack, N. Y.

5 *Nassau beds* (divisions A–E of Dale's series in Rensselaer county). In Rensselaer county the Olive grit or Bomoseen grit is underlain by a series of alternating reddish and greenish shales and quartzites containing *Oldhamia*, about 150 to 800 feet thick. This is especially well exposed in the town of Nassau, N. Y.

6 *Diamond Rock quartzite* (division G of Dale's Rensselaer series). This division 10 to 40 feet thick and composed of granular quartzite and associated calcareous sandstone, is well exposed in Oakwood cemetery and the "Diamond Rock" in Lansingburgh (North Troy), from which it takes its name.

7 *Troy shales* (division H of Dale's Rensselaer series). This formation, which follows upon the Diamond Rock quartzite, consists of 25 to 100 feet of colored shales with small beds of calcareous quartzite. The shale has furnished *Oldhamia*, a calcareous sandstone bed in the upper part *Hyolithes* and *Hyolithellus*. These beds are well exposed at Troy, at the dam in the Poesten kill and other localities.

8 *Zion Hill quartzite* (Ferruginous quartzite Dale). This name, taken from Zion hill, Hubbardtown, Vt., where according to Dale the ferruginous quartzite is exposed in a thickness of 70 feet, is proposed here for the sake of completeness.

On the Schuylerville sheet we find well represented only division A and the limestone and shales of D. We have separated the areas occupied by these two divisions on the map, the boundaries being only approximate on account of the interfolding of the beds.

The olive grit occupies the southern half of the area. It is easily recognized by the pale brick-red color of the weathered crust that forms on it; typically it is seen on the many ledges north of Greenwich, but it also appears on all sides of Louse hill and extends to the southern boundary of the Georgian areas. From Greenwich the grit skirts the eastern side of Bald mountain. It is described by Dale as follows:

A greenish, usually olive-colored, very rarely purplish, more or less massive grit, generally somewhat calcareous, and almost always spangled with very minute scales of hematite or graphite. Under the microscope it is seen to consist mainly of more or less angular grains of quartz, with a considerable

number of plagioclase grains, rarely one of microcline, in a cement of sericite with some calcite and small areas of secondary quartz. There are large scales of muscovite and of a chloritic mineral, scarcely dichroic, and under polarized light a bluish green or prussian blue, with little or no change in rotation. More conspicuous and typical of the rock are scales from 0.043 to 0.130 by 0.020 millimeter, frequently bent, pale green, markedly dichroic, and under polarized light olive or slightly bluish green. These scales contain bands of a colorless mineral parallel to their cleavage, which measure 0.0043 in width and polarize in brilliant orange, emerald or blue. Extinction in both about (if not quite) parallel to cleavage and bands. Finally, there are grains or crystals of a muddy yellow under incident light, probably limonite and that after hematite. The scales of hematite, sometimes graphite, can be made out with a magnifying glass.

This characteristic rock can usually be identified at a distance by the peculiar pale brick-red color of its weathered surface, and, on closer inspection, by the minute spangles and the olive color of the fresh surface.

The olive grit has not furnished any fossils, but it was found full of carbonaceous blotches, suggesting seaweeds, and large worm trails. It is apparently a shallow water deposit.

The belts of heavier grit beds alternate with belts of more slaty, often brownish weathering beds, apparently resulting from the grit through a stronger development of the cleavage. These belts were found to be worn down more, forming the depressions between the ridges of harder grit.

The hills composed of this rock are frequently discerned from a distance through the reddish color of the soil they furnish. The Georgian limestones were also found to weather into soils of reddish tints so that as a whole the Georgian areas of this region can, to a large degree, be distinguished from the Ordovician shale areas by the soils, wherever the drift is thin or its lower portion exposed, for, as a rule, this also contains so much material derived from the underlying rocks that it partakes of the reddish color. The olive grit forms a belt beginning at the projecting southeast corner of the Georgian area south of Louse hill, continuing over Louse hill and exposed on its north slope, on the banks of the Batten kill, continuing north of Greenwich to the central and eastern peaks of the Bald mountain ridge.

South and east of Louse hill the olive grit or the Bomoseen is flanked by massive ledges of gray quartzite speckled with brown spots of limonite. We consider this bed as corresponding to the massive beds of quartzite found farther east by Dale in association with the Bomoseen grit. On the centre peak of Bald mountain, the Bomoseen grit is flanked on both sides by quartzite beds which are

followed by the shales and limestones of the Schodack beds, the whole probably forming an overturned abraded fold. This section would then indicate that the normal sequence is Bomoseen grit, Bomoseen quartzite, Schodack shales and limestone.

None of the typical roofing slates of the eastern part of the slate belt were observed in the Cambrian area, but beds of calcareous quartzite, and especially brecciated limestones observed in connection with the Schodack beds, may represent this division.

The Schodack beds are especially well seen in the northern Georgian area of the sheet, where the black and gray shales and the interbedded limestones are everywhere exposed along the road skirting the base of the Georgian plateau in the town of Argyle. This area includes the well-known Bald mountain locality, where the black shales are seen with a thin quartzite bed directly above the quarry on the west side, while on the south side the olive grit has been drawn along the fault line into the shales. On the western slope of Bald mountain the thick-bedded, bluish limestones and interbedded dark gray to black partly arenaceous shale of the formation are well exposed.

Walcott, in his monumental monograph of the Cambrian Brachiopoda (1912, page 197), records the following species from this neighborhood:

1 Limestones 1.5 miles (2.4 Km.) north of Bald mountain:

- Obolus prindlei* (Walcott)
- Lingulella granvillensis* Walcott
- Obolella crassa* (Hall)
- Botsfordia caelata* (Hall)
- Acrotreta sagittalis taconica* (Walcott)
- Stenotheca rugosa* (Hall)
- Platyceras primaevum* Billings
- Hyolithellus micans* Billings
- H. micans rugosa* Walcott
- H. communis* Billings
- Elliptocephala asaphoides* Emmons
- Solenopleura tumida* Walcott

2 Shaly limestone on the west slope of the summit of Bald mountain:

- Botsfordia caelata* (Hall)
- Acrotreta emmonsi* Walcott
- Olenellus* sp.

Professor Cushing and the writer collected a number of the species here recorded from the first locality and also on Bald mountain.

North of Bald mountain the thin-bedded, bluish (50+ feet thick) limestone is seen in sections to grade into more massive light gray limestone beds which, exposed in cliffs at the fault line, are liable to be confounded with the Bald Mountain limestone and may have led to the extension of the "Trenton" limestone belt farther northward than shown on our map. Georgian brachiopods were found in this massive limestone bed in at least two localities. These limestones were seen in several places to rest on black Cambrian shales. It is therefore probable that the Schodack beds contain here some thicker limestone beds than observed in the more eastern region.

The area southeast of Louse hill consists of black shale, a thin-bedded limestone with shale seams and quartzitic bands, with a great number of quartz veins.

Dark gray shales with brecciated limestone pebbles, the beds reaching 200 feet or more (assuming no repetition) in section given on page 81, are exposed at the west edge of the Bald mountain quarry and in the sections north of it. They are interfolded with the Bald Mountain limestone and Rysedorph Hill conglomerate, but have the appearance of the Schodack beds, and are probably Georgian beds forced into the Ordovician belt near the overthrust plane.

SCHAGHTICOKE SHALE

The Schaghticoke shale with its characteristic faunule, consisting of *Dictyonema flabelliforme* and *Staurograptus dichotomus* Emmons var. *apertus* Ruedemann was discovered by us in a cut of the Hudson Valley Railroad, near the mill of the Standard Wall Paper Company about a mile north of Schuylerville, and thence traced across the lower part of the rapids of the Hudson below Thomson. The entire belt is probably not more than 1000 feet wide and bounded on both sides by outcrops of Normanskill shale; its length is unknown since it runs in both directions under the drift. The rock in the exposure is much contorted and consists for the most part of light greenish gray, glazed argillaceous shale that weathers to a light drab or whitish color with intercalations of coarser light bluish gray more or less sandy mud shale and small streaks of black shale containing the graptolites. It also contains a $3\frac{1}{2}$ feet bed of coarse grit with black calcareous and argillaceous pebbles and large, floating, rounded sand

grains. One part of the formation is characterized by a number of calcareous sandstone beds $\frac{1}{8}$ to 1 foot thick, which weather into a characteristic chestnut-brown sandy crust. Through the contortions of the beds these rocks are mostly broken into strings of brown boulderlike blocks.

In the river bed where the beds are seen on edge, they appear as greenish gray shales with frequent black shale bands and brown calcareous sandstone beds and some thicker beds of argillaceous mudrock.

These Schaghticoke shales of Schuylerville very much resemble in the alternation of the greenish gray and black argillaceous shales, giving the outcrops on edge a very characteristic banded appearance, the typical Schaghticoke shale as described by the author from the bed of the Hoosic river at Schaghticoke, lacking, however, the intercalated thin limestone bands observed there. They are distinguished from the surrounding Normanskill shale by the absence of white-weathering chert layers and the presence of the chocolate-brown weathering calcareous sandstone; but of course none of these criteria is sufficient to recognize them without the fossil evidence. It is for this reason that they may be outcropping in other localities without having been recognized.

When the author described the *Dictyonema flabelliforme* or Schaghticoke shale,¹ he followed the consensus of the preceding European authors who considered the shale with *Dictyonema flabelliforme* as marking the top of the Cambrian. Since that time stratigraphers have, especially in Sweden, advanced arguments for placing the *Dictyonema* bed at the base of the Ordovician, a proceeding which would also seem to agree well with the condition in the slate belt, since the *Dictyonema* shale is on one hand separated by a great hiatus from the underlying Georgian, but on the other by its lithologic character and probably also stratigraphically is closely connected with the following Deep Kill shales. Lately Ulrich² has also argued for the close stratigraphic connection of the *Dictyonema flabelliforme* zone with the *Tetraraptus* zone (the lowest of the Deep Kill zones), and placed the *Dictyonema flabelliforme* zone in his Canadian system (which comprises the Tribes Hill limestone and Beekmantown B-E).

¹ Ruedemann, R. Cambrian *Dictyonema* Fauna in the Slate Belt of Eastern New York. Pal. Rep't (for 1902) 1903, p. 934.

² Ulrich, E. O. Revision of the Paleozoic Systems, pts 1-3. Geol. Soc. Amer. Bul., v. 22, no. 3, p. 678.

DEEP KILL SHALE

The Deep Kill shale has not been recognized anywhere on the two quadrangles, but since it lies in the stratigraphical series between the Schaghticoke and Normanskill shales, it is quite possible that small parts of this formation, like that here observed of the Schaghticoke shale, may have been forced up through the extremely disturbed belt of Normanskill shales. Also in this case, the finding of the characteristic graptolites would furnish the only conclusive evidence of its presence, although the lithologic characters of the Deep Kill shale are such that where well exposed they are readily recognized.

BALD MOUNTAIN LIMESTONE ¹

At the western foot of Louse hill near the southwestern corner of the Georgian area, a belt of dolomite and limestone appears on the surface. It can thence be traced northward for about a mile, when it disappears under drift but its presence below the latter is still indicated through the frequent limestone boulders in the drift seen in the stone fences. It then is again well exposed in the ridge skirting the west bank of the Batten kill at its bend south of Middle Falls, in the village of Middle Falls where it causes the fall in the river, and north of Middle Falls in many hillocks protruding through the drift on both sides of the road from Middle Falls to Bald mountain. An excellent locality rich in fossils was found by the writer in an abandoned quarry on the north bank of the Batten kill a quarter of a mile above the village. In front of Bald mountain the beds are now best exposed by the large quarry operations which were carried on there formerly to supply the material for two limekilns still standing west of the road skirting the mountain on the west. From Bald mountain the beds are traceable but half a mile as indicated on the map, but may reappear farther north beyond the limits of the sheet. Southward of Louse hill, this belt fails completely on the west edge of the Georgian in Washington and Rensselaer counties.

This limestone belt is in the neighborhood of Bald mountain, that is at the Bald mountain quarries and northward accompanied by a conglomerate which we have identified with the Rysedorph

¹ Grabau in his paper on the Physical and Faunal Evolution of North America during Ordovician, etc. Time (Jour. of Geol. 1909) cites a "Bald Mt" formation in the correlation table I, p. 251, but on reference to the text (p. 235) it is seen that the "Bald Eagle (Mountain)" conglomerate is meant.

Hill conglomerate, described by the writer from the neighborhood of Albany (see page 80).

This belt was probably first noted by Emmons who indicated it on his map accompanying his Agricultural Report¹ and gave a section through Bald mountain in his paper on the Taconic series in the same report. He identified it with the "Calciferous sandstone" (Beekmantown), distinguishing a blue portion of purer limestone and a lighter one. He included, however, the thin-bedded limestone on top of the mountain in the "Calciferous sandrock." This latter has been shown by Walcott (*op. cit.*, page 317) to be of Cambric (Georgian) age, a fault separating the Georgian rocks from the limestone belt (see chapter on structure of Bald mountain, page 108). Walcott, who first correctly separated on a map the Ordovician and Lower Cambric areas of the slate belt (*op. cit.*, plate 3), also indicated the extension of the limestone belt and gave a section of Bald mountain in which he distinguished "Calciferous sandrock" (the lower darker rock) separated by dark shales from "Chazy limestone." From a locality (*op. cit.*, page 317) about 2 miles north of Bald mountain, Trenton fossils (*Dalmanella testudinaria*, *Rafinesquina alternata*, *Mac-lurea* and other gastropods, *Calymmene senaria* and fragments of *Asaphus platycephalus*) are cited. It is thus seen that Walcott held the view that the limestone belt contains Calciferous, Chazy and Trenton rocks, a view also expressed on plate 3. Dale has on his map of the slate belt (1899, plate 13) distinguished the limestones simply as lower Siluric (Ordovician) limestone from the Lower Siluric shale, etc., stating (page 190): "The Trenton limestone occurs sporadically within the Ordovician areas of the slate belt; also on its western edge in Argyle and in Hartford. In some places it was probably deposited contemporaneously with the Hudson grit and shales, or it may underlie a portion of them. In others it may represent the entire Lower Silurian series and should then be regarded as Trenton, Chazy and Calciferous."

We see from this quotation that the determinations of the age of the Ordovician limestone in the slate belt are rather insecure, a fact that can be readily explained by the scarcity and poor preservation of the fossils usually obtained there.

On the Geologic Map of New York, published by F. J. H. Merrill (1901), the limestone belt on the west edge of the Georgian is entered simply as Trenton.

¹ Emmons, Ebenezer. Agriculture of New York, v. 1, 1846.

As far as the part of the limestone belt on the Schuylerville sheet is concerned, our collections have shown that one must there sharply distinguish between the dolomite and limestone on one hand, and the conglomerate on the other, for the former have only furnished fossils of Beekmantown age, and the latter such indicating Black river to Trenton age.

The principal fossiliferous outcrops of the limestones are found in the neighborhood of Middle Falls. The most important one is an old quarry, one-quarter of a mile above the village at the bend of the river, where about 25 feet of highly fossiliferous limestone are exposed. This locality has furnished:

Cryptozoon *sp.*

Girvanella *sp.*

Undescribed sponges

Eccyliopterus planidorsalis *Ulrich* MS

E. planibasalis *Ulrich* MS

Oxydiscus *sp. nov.*

Hormotoma? (*Murchisonia*) *cassina* (*Whitfield*), section
Segments of trilobites

A small knoll at the northern outskirt of Middle Falls was found to contain specimens of

Polytoechia apicalis (*Whitfield*)

cf. Protorthis minima *Whitfield*

Along the road from Middle Falls to Bald mountain, dolomite and limestone outcrops are observed on both sides; one of these, west of the road and halfway between Bald mountain and Middle Falls, contained in the limestone, ostracods (undescribed species of *Primitia* and *Leperditia*) and fragments of trilobites.

The limestone of the Bald mountain quarry contains cephalopods and gastropods, namely:

Cryptozoon *sp.*

Eccyliopterus planidorsalis *Ulrich* MS

E. planibasalis *Ulrich* MS

Liospira? *sp.* (section)

Cameroceas brainerdi (*Whitfield*)

Cyrtoceras confertissimum *Whitfield*

Cephalopod and gastropod sections were also observed in a small quarry on the roadside at the west foot of Louse hill.

These faunules demonstrate the Beekmantown age of the limestone and indicate that it is to be correlated roughly to the Fort Cassin beds, which correspond to unknown parts of Brainerd & Seely's divisions D and E. Since, however, this belt of Beekmantown rocks fully corresponds to the Fort Cassin beds, neither in its lithology nor in its faunal aspect or its stratigraphy, we consider it unsafe to correlate it with the Fort Cassin and shall designate the beds as *Bald Mountain* limestone.

The fauna of the Bald Mountain limestone is distinct from the Fort Cassin fauna, on the one hand in the entire absence of the coiled nautiloid cephalopods so characteristic of that fauna, and, on the other hand, by the prevalence of striking *Eccyliopteri*, which, according to Ulrich, are identical with forms occurring in the Canadian of Missouri.

The Bald Mountain limestone can neither be correlated nor be continuous with the limestones and dolomites outcropping at the foot of the Adirondacks only a short distance to the west on the Saratoga quadrangle, since these beds, though formerly referred to the Calciferous or Beekmantown, are now known to represent only the lowest division A, and perhaps part of B, which are separated by a great unconformity from the Beekmantown and are claimed even to belong to another system (Ozarkic of Ulrich). It is possible that the Bald Mountain limestone finds its continuation 80 miles farther south in the Wappinger limestone in southeastern New York, but the latter belt includes limestones of Hoyt, Beekmantown, and Mohawkian ages, and the name is therefore not applicable to the possible northern continuation of its Beekmantown portion.

The lower part of this formation consists of dark gray (but sandy gray when weathered), massive, often sandy and also brecciated, practically barren dolomite¹ of which we have seen 40 feet or more, some in beds as much as 6 feet thick. It is well seen in several places, namely, an old quarry on the west bank of the Batten kill half a mile south of Middle Falls, in an abandoned quarry on a hill at the west foot of Louse hill $2\frac{1}{4}$ miles south of Middle Falls and in a quarry by the road south of Bald mountain. This, like all the limestone and dolomite on Bald mountain, is referred to the Calciferous by Emmons and it is the Calciferous sandrock of Walcott's Bald Mountain section. It is in the neighborhood of Bald

¹A few sections suggestive of cephalopods and *Ophileta* were observed in calcareous layers.

mountain now best exposed near the two road crossings, the one just west and the other just south of Bald mountain, near the latter crossing in a quarry. The dolomite in the former outcrop is, on account of the complicated overturned and recumbent fold structure of the limestone belt, apparently separated from the limestone by shale beds (see page 109) and so represented by Walcott. The aspect of the dolomite which also contains considerable chert reminds one of the Little Falls dolomite. It is, however, not to be separated as a unit from the limestone, for the two were found to be grading into each other on the road from Middle Falls to Bald mountain and also along the road south of Middle Falls. One instructive locality, a small quarry alongside the road, at the west foot of Louse hill, furnished the following section in descending order:

Thin-bedded limestone	4 feet
Massive limestone bed	3½ feet
Brecciated limestone with gastropods	3 feet
Dolomite bed with irregular band of limestone in middle, full of narrow chambered cephalopods	2 feet, 4 inches
Dolomite bed	1 foot, 2 inches
Brecciated limestone	3 feet

Of the limestone we have seen in one place (west of Louse hill) 70 feet in continuous section, with the top and bottom not exposed. It may therefore reach 100 feet in thickness. It is for the most part fine grained, sometimes approaching the dove-colored limestones, light bluish gray in color with many white crystalline spots. In the lower part it contains somewhat arenaceous bands. It resembles some of the limestone of D of the Champlain valley and also some of the Middle Chazy rocks. Emmons referred it to the Calciferous sandrock (Beekmantown). Walcott designated it as Chazy limestone in the Bald Mountain section, but stated (1888, page 317) that about 2 miles north of Bald mountain similar rocks contain Trenton fossils. Dale (1889, page 190) also refers to this limestone as Trenton limestone but mentions that in some places it may represent the entire Lower Siluric series and should then be regarded as Trenton, Chazy, and Calciferous. On the Schuylerville quadrangle the limestone is as the above given fossil lists show, throughout of Beekmantown age. There is, however, no doubt that also in other parts of the slate belt limestone of Trenton, or at least Mohawkian, age outcrops. The presence of such

is also indicated by the Rysedorph Hill conglomerate, occurring at Bald mountain with its Mohawkian fauna.

The stratigraphic relation of the Bald Mountain limestone to the shales is nowhere apparent, the observed contacts between the two being along fault planes. Thus the limestone is seen to rest by a westerly rising plane on the folded Snake Hill shales below the falls at Middle Falls; since the shales are younger than the limestone, the latter is here overthrust on the shale. The interbedding of shale between the dolomite and shale, assumed in Walcott's Bald Mountain section, is due to a mass of shale folded or thrust locally into the Bald Mountain limestone. The limestone belt is on one side bounded by the shale, on the other by the Georgian rocks; and, as a glance at the map will show, it ends abruptly where the edge of the Georgian overthrust blanket southwest of Louse hill turns east, suggesting that this overthrust mass brought the limestone with it (see postea page 110). We have thus, principally from the fossil evidence, to assume that the Bald Mountain limestone, which surely is older than the Normanskill shale, overlies the Deep Kill shale. But it may come from an entirely different trough or basin, that originally was east of the Levis trough.

RYSEDORPH HILL CONGLOMERATE

Associated with the Bald Mountain limestone in the Bald Mountain section and for 2 miles north of it, occurs a conglomerate of striking character. It is best exposed at the north end of the Bald Mountain quarry, and along the brook skirting the north side of the mountain, below the road. The rock consists of a black mud matrix. In it float without assortment pebbles of all sizes, from that of a pea to those 2 to 3 feet in diameter. The smaller pebbles are well rounded, the larger ones subangular with rounded edges. They are in part the Georgian limestone, but also deep blue dolomite and gray and dove limestones. A few of the pebbles have furnished fragmentary fossils which indicate the Trenton age of these pebbles. The fossils were:

Lingula sp. (fragment)

Siphonotreta cf. *minnesotensis* Hall & Clarke

Rafinesquina sp. (fragment)

Plectambonites *pisum* Ruedemann

Ceraurus cf. *pleurexanthemus* (Green), fragment

Bythocypris *cyindrica* (Hall)

Isochilina *armata* Walcott var. *pygmaea* Ruedemann

In the matrix there was also obtained a specimen of *Plectambonites pisum*, a species known from the Rysedorph Hill conglomerate at Rysedorph hill. As this conglomerate contains pebbles of various ages, from the Georgian to the Mohawkian, like that of Rysedorph hill, and lies in the northern continuation of the latter and apparently, also as this latter, above or in the upper Normanskill shale, we have identified the Bald Mountain conglomerate with the Rysedorph Hill conglomerate.¹ The occurrence of *Plectambonites pisum* common to both outcrops also supports this view.

We surmise that the Trenton fossils formerly recorded from the limestone north of Bald mountain came from this conglomerate.

The conglomerate at Bald mountain may reach a considerable thickness; in the quarry it is in one place over 20 feet thick, but it is impossible to say how much the folded condition contributes to this thickness. Along the brook northwest of Bald mountain we observed the following section from east to west, the beds being nearly all vertical:

1	Cambric shale	
2	Covered	90 feet
3	Limestone with some quartzite and breccia	55 feet
4	Covered	270 feet
5	Conglomerate with large pebbles	45 feet
	Trenton fossils and calcareous matrix	
	Rysedorph Hill conglomerate	
6	Calcareous shale and shaly nodular limestone	
	(Georgian)	200 feet
7	Covered	70 feet
8	Conglomerate with large pebbles	75 feet
9	Covered	

It is possible that the conglomerate bed in no. 8 is folded upon itself, and in no. 5 the simple thickness of the bed is exposed. It is there about 45 feet thick.

While this conglomerate in its outcrops adjoins the Bald Mountain limestone, its fossils indicate that it is younger than the typical Normanskill shale and intervenes in age between this and the Snake Hill shale. It therefore should be separated from the Bald Mountain limestone by the Normanskill shale. On Rysedorph hill the

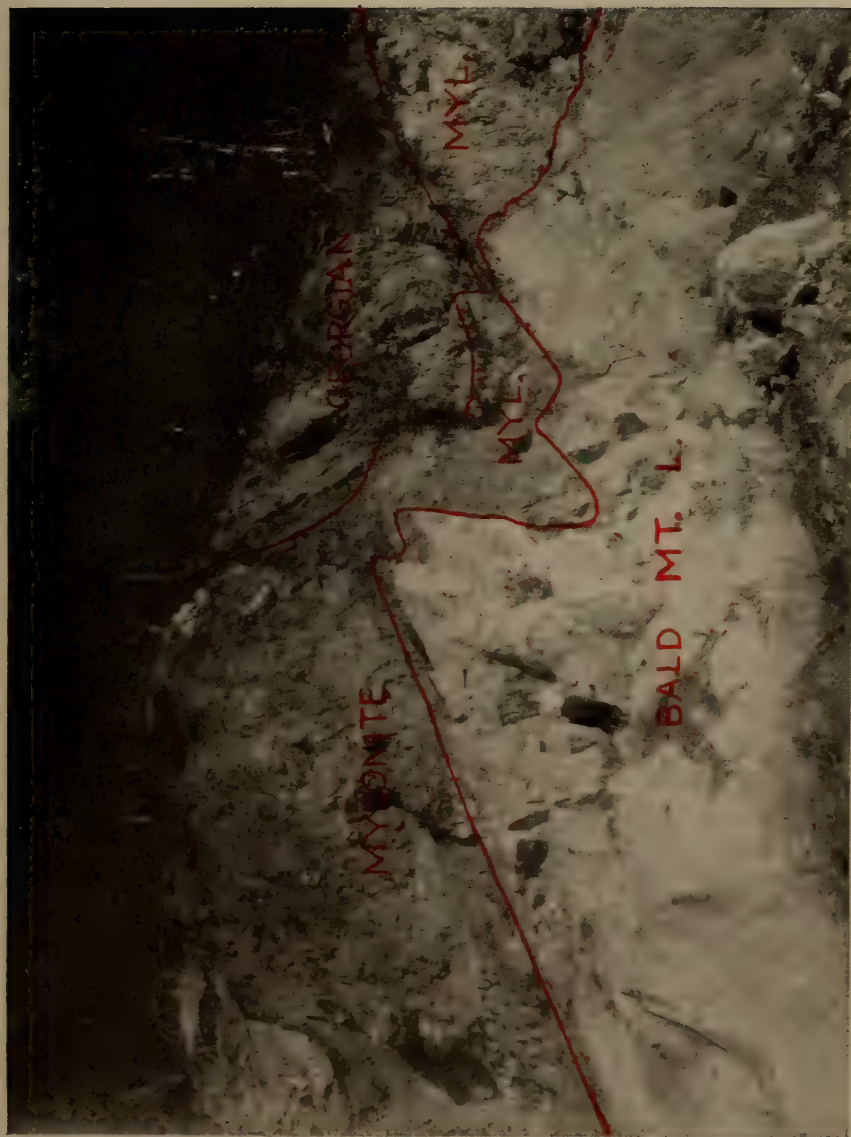
¹ Ruedemann, R. Trenton Conglomerate of Rysedorph hill. N. Y. State Mus. Bul. 49, p. 3.

conglomerate also outcrops so near the overthrust fault of the Georgian that it might well be a block caught in the fault, although it is there underlain and overlain by shale of presumably Normanskill age. At the Moordener kill a few miles south from Rysedorph hill, it is seen five times repeated in the section and apparently folded in with Normanskill shales 1 to 2 miles away from the overthrust fault. Another fine exposure of this conglomerate which also has furnished *Plectambonites pisum* is seen in the shore cliffs at Papscanee island, about 5 miles below Albany. This outcrop¹ is at least 2 miles away from the overthrust plane, and another good exposure at Schodack Landing is equally distant. The typical Rysedorph Hill conglomerate southeast of Albany is thus too far away from the thrust fault on which the Georgian was brought westward to be considered as having been brought along this plane, and it is seen in a number of places clearly intercalated in the Normanskill shale as an intraformational conglomerate.

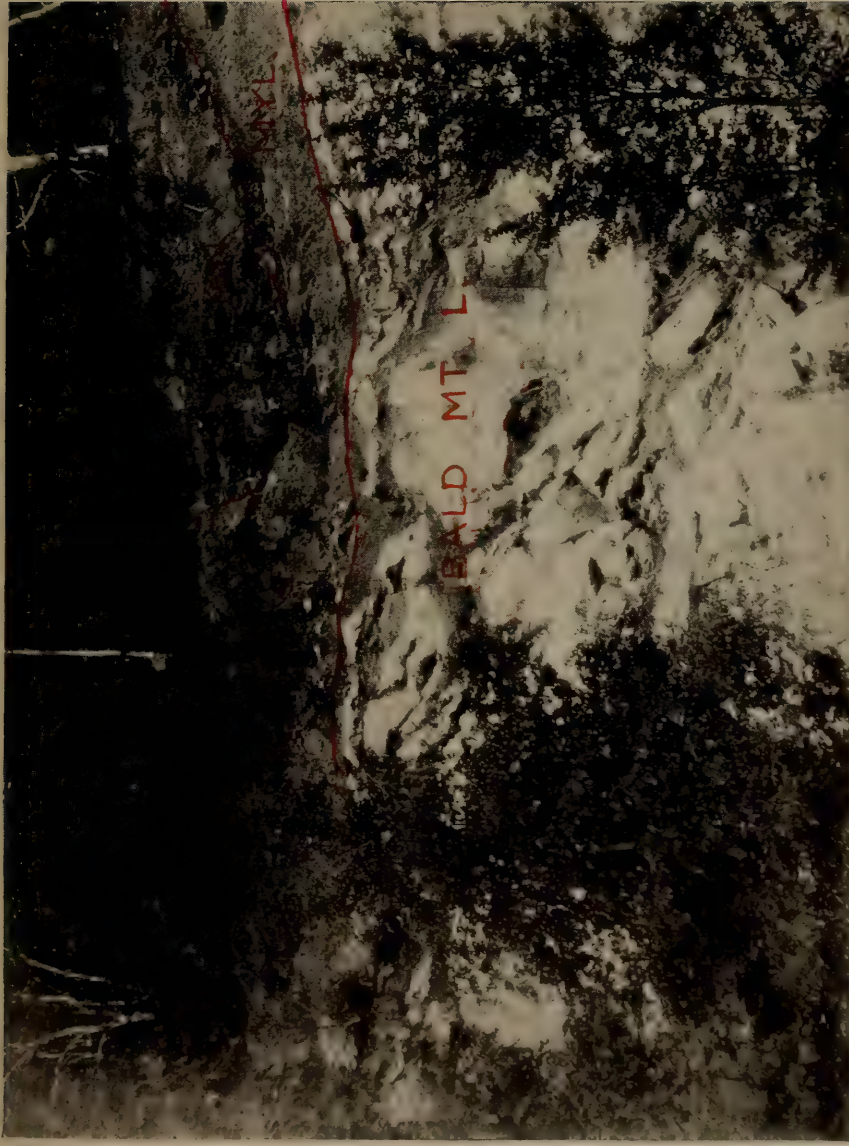
Whatever may be the origin of this remarkable rock, the character and variety of the pebbles and the character of their faunules indicate, as we have shown in the paper on the Rysedorph Hill conglomerate, that they are derived from beds not now exposed in the slate belt and probably brought from the east, especially since the fossils are of Atlantic type. The age of the conglomerate which in museum Bulletin 42 had been held to be lower to middle Trenton, is from the aspect of the faunules of both the youngest pebbles and the matrix, probably greater and corresponding to the Black river. The Normanskill shale with which it is associated in the Rysedorph hill and Moordener kill localities, has been found by Ulrich in the Athens trough to be upper Chazyan in age. We have therefore considered the conglomerate as originally overlying the Normanskill shale and thus represented it in the diagram, text figure 15. Investigations, however, carried on since have brought out the fact that the Normanskill shale embraces two formations, as is more fully stated below (page 93) and that the Rysedorph Hill conglomerate is intercalated in the upper division of Black River age.

The peculiar fauna which was described from this conglomerate by the writer has been recognized in part in the Chambersburg limestone of Pennsylvania of the Chambersburg-Massanutten and

¹ This exposure while then known to the author, was accidentally omitted in Bulletin 42.



R. Ruedemann, photo, 1911
View in northern part of western face of Bald Mountain quarry, showing the Bald Mountain limestone, overlain by irregular masses of mylonite or fault-brecciated material and Georgian.



R. Ruedemann, photo, 1911

View of southern part of western face of Bald Mountain quarry, showing the Bald Mountain limestone overlain by a sheet of mylonite on which in turn rest Georgian rocks that in the quarry, through their red-brown color, contrast more sharply with the black fault-breccia than in the photograph. The uppermost beds of the Bald Mountain limestone are seen to be torn into strings of blocks as if in the process of being incorporated into the breccia.

Plate 14



R. Ruedemann, photo, 1911

View in the southern face of the Bald Mountain quarry, showing the irregular faulted and broken cliffs of Bald Mountain limestone projecting into a thick mass of mylonite which carries a continuous blanket of much crumpled Georgian grit beds (Bomoseen beds)

Mercersburg troughs and farther south.¹ Since, however, the Chambersburg limestone does not continue in the Levis trough north of Pennsylvania, the conglomerate can not be referred to as constituting a northern continuation or a part of the Chambersburg limestone and it appears that the Atlantic fauna found in the Rysedorph Hill conglomerate was able to enter the troughs between the Appalachian barriers from the east in several independent places.

The conglomerate about Bald mountain, which is here correlated with the Rysedorph Hill conglomerate is clearly bound to the large overthrust plane, for at Bald mountain itself it is associated with the Bald Mountain limestone, and to the north of it it is even infolded with Georgian shales. As we have already stated, it is here exposed only close to the great overthrust fault and by the latter brought in juxtaposition with the Bald Mountain limestone and Georgian rocks. This position is probably due to its greater resistant power as compared with that of the softer shales, which have been ground up.

Besides this conglomerate, the matrix of which consists, as at Rysedorph hill, largely of sandy lime, there is observed at Bald mountain a breccia of remarkable appearance and thickness. This is seen in plates 12-14 between the Bald Mountain limestone and the Georgian in very irregular masses. It is best exposed on the south face of the quarry, where it reaches 30 feet in thickness in one place and can be easily studied since it descends to the bottom of the quarry. It consists here of an utterly unstratified black mud matrix with numerous unassorted small more or less angular pieces, mostly of the size of a pea or smaller, of limestone, olive grit, chert etc. (see plate 15, which is a photo of a hand specimen). The matrix has the appearance of a thoroughly ground up shale mass and with pebbles floating in it, resembles a tillite. There is, however, no doubt that this mass is the result of the tremendous friction at the base and between the masses of Georgian rocks on top and the Bald Mountain limestone below, which were moved on a nearly horizontal plane. How the top beds of the Bald mountain limestone were torn off and incorporated in the shale is well shown in plate 13, where strings of Bald Mountain limestone are seen to reach into the black mudrock in the process of being torn up. The black soft

¹ Stose, G. W., Mercersburg-Chambersburg folio, Pa. U. S. Geol. Surv., folio 170, 1909. Bassler, R. S., The Cement Resources of Virginia, West of the Blue Ridge. Va. Geol. Surv. Bul. 2, 1909. Ulrich, E. O., Revision of the Paleozoic Systems, pts. 1-3. Geol. Soc. Amer. Bul. v. 22, no. 3. 1911.

mudrock is the result of the grinding up of the black Georgian shale and of Snake Hill and Normanskill shales on both sides of the thrust fault.

Törnebohm (1896) has first shown how the rocks are ground into flour along the great overthrust planes. He terms this flour "Friktionsbrei" (mylonite) stating that it served as "Schmiermittel" (lubricating substance) during the overthrusting and that its thickness depends on the obstacles in the mass that is overridden. In the French central plateau these masses are said to reach several hundred meters in thickness.

That in Bald mountain the conditions that rest in the resistance of the underground were especially favorable for the accumulation of the mylonite, is distinctly shown by the bulging up of the Bald mountain limestone mass there, the limestone, together with the overlying Georgian rocks, descending north and south of the face of the Bald mountain quarry, away from the mountain.

THE NORMANSKILL SHALE

This graptolite shale which has received its name from the exposure at the Normans kill at Albany, forms two belts on the Schuylerville quadrangle, one, entirely surrounded by Snake Hill beds, coming up from the Cohoes quadrangle and terminating near the mouth of the Batten kill, and another south of the Georgian overthrust mass, culminating in Willard mountain.

As in the entire shale belt in the Hudson River valley, the greater part of the Normanskill formation consists of blue to gray, mostly argillaceous, often more or less sandy shales, with thin intercalations of black, highly carbonaceous graptolitiferous and frequently pyritiferous shales; the lighter bluish gray and black shales often giving the rock a banded appearance in the common edgewise view.

Where these shales are brought up from such depths that they are still fresh and unaffected by surface weathering and frost, they appear quite different, as more or less compact bluish gray and black mudrocks. Considerable material of this character was seen at the new canal locks above Schuylerville and in other places.

The shales of the Normanskill formation include, however, two other kinds of rock in such quantities that their frequent appearance in outcrops can be considered as quite characteristic of the formation. These are the "white weathering cherty beds" and the grit.



Hand specimen of mylonite from Bald Mountain quarry, showing the compact structure of the argillaceous matrix, with the numerous small fragments of limestone and dolomite floating in it and seen on the weathered surface. On the left an obscure cleavage is seen. Natural size.

H. P. Whitlock, photo



H. G. Whitlock, photo

Specimen of Lower Cambrian rock from the top of the south face of the Bald Mountain quarry. The upper view shows the small slip faults producing offsets on the bedding plane that appear as broader light bands in the photograph.

The lower view shows the other side of the same slab; it is so illuminated that the numerous small ripples parallel with the fault planes are seen. They result from the shoving of the specimen in the overthrusting along a plane oblique to the bedding plane which forms the surface of the slab. Both views reduced one-fifth.

The white weathering cherty beds. Associated with the black shales of the Normanskill formation occurs a series of very hard, splintery, dark to light greenish or black, cherty-looking beds which weather with very light gray or white crust. These siliceous beds frequently through their greater hardness, stand out as white ridges and form characteristic landmarks. According to Dale (*op. cit.*, page 186) the white surface gives the reaction for kaolinite¹ and the rock was probably originally a feldspathic mud, with quartz fragments and muscovite scales; the latter two appearing under the microscope as the principal constituents of the cherty beds.

The finding of Normanskill graptolites in the white beds at several places on the Schuylerville sheet, notably in a small creek just above Coveville and northeast of Willard mountain, leave no doubt of the Normanskill age of the principal mass of the cherty beds. There is, however, no doubt that similar cherty layers occur also, though rarely, in the Snake Hill formation and that all transitions occur from the common argillaceous shales through slightly more siliceous and whitish weathering shales to the thick-bedded, white-weathering cherty layers.

On account of their great hardness the white beds most frequently form the tops of ridges and can often be traced for some distance along the strike of the folded beds. The more important outcrops of white beds have been indicated on the map by the blue symbols. These show that the principal areas of chert outcrops are the region extending from Coveville northward to Thomson and Northumberland and that of the Willard mountain ridge in the southeast corner of the quadrangle. In the former the most striking chert ridge is seen $1\frac{1}{2}$ miles west of Victory Mills. This forms cliffs seen from the Schuylerville branch of the Fitchburg Railroad, in which are solid beds of the cherty or siliceous rock 30 feet and more thick. Other smaller ridges of white beds protrude through the drift one-half of a mile west of Victory Mills and on the water-swept plateau north of Coveville. Also south and north of the Northumberland plug appear ledges of the harder cherty beds on the hillsides and a small outcrop of very thick-bedded, deep black chert was found just west of the entrance of the Hudson river bridge at Thomson.

¹According to a later statement by the same author (1904, p. 36) the weathering white of the chert may be due either to the loss of carbon or to the kaolinization of a fine feldspathic cement.

The other belt of thick and prominent outcrops of white-weathering cherty beds extends across Willard mountain and forms the backbone or top of the high ridge extending north from Willard mountain, obviously one of the causes that this steep landmark has withstood weathering so much better than the surrounding land. On top of Willard mountain itself, a ridge about 150 feet wide of white-weathering, vertical or steeply inclined synclinal beds is found. The high cliffs on the west brow of Willard mountain consist principally of this chert, which is again finely exposed on the road crossing the ridge north of Willard mountain. It extends here along the crest of the ridge to the north point. Another ledge strikes about a mile east of Willard mountain.

A ridge of white beds begins also north of Snake hill at the shore of Saratoga lake and can be recognized again 2 to 3 miles farther northeast. At the lake shore a solid 3 foot bed of black chert was found intercalated in fissile dark shales. This chert contained *Climacograptus bicornis*, *Glossograptus*, *Climacograptus modestus*, but not the *Dicellograptus nicholsoni* that occurs all along the lake shore in the shales. It would thus seem to be also of Normanskill age, although it is surrounded by Snake Hill beds. Farther northeast a thickness of over 20 feet of this chert has been observed on top of the ridge.

The graptolites in the chert are not preserved as carbonaceous or pyritized remains as in the argillaceous shales, but are as white as the weathered surface of the rock and, wherever present, show a striking contrast with the dark rock. It is possible that they are also kaolinized, but they may also be composed of the mineral gümbelite, a greenish white silicate which has been found in Bavaria to have sometimes replaced the carbonaceous tests of graptolites.

The Normanskill grit. The white-weathering chert beds are always associated, on the Schuylerville quadrangle at least, with the Normanskill grit. As in the case of the cherty beds, grit beds are also present, though in much less development, in the Snake Hill formation. These grits of both formations have been carefully described as Hudson grit by Dale (1899, page 187), from whom we quote:

The Hudson grit is a rock so marked in its characteristics as to be easily identified. It is coarse, grayish, sandy looking. Fresh fracture surfaces are very dark and show glistening glassy quartz grains and very

frequently minute, pale, greenish, slaty particles. Under the microscope, it consists of angular grains of quartz, orthoclase, plagioclase, and scales of muscovite, probably clastic. The cement contains not a little carbonaceous matter, secondary calcite, and pyrite. In the more easterly Ordovician area the cement is quite sericitic and the feldspar is partially sericitized, but in other places and along the Hudson, in Rensselaer county, the amount of sericite in the cement is small. The marked features are the heterogeneity of the fragments, their irregular size, angular outline, and usually the absence of any arrangement in them. Chloritë is rarely present.

A further peculiarity of the Hudson grits is that they contain particles of various fragmental rocks, showing that they were derived from the erosion not only of older granites and gneisses, but of sedimentary rocks of Ordovician or pre-Ordovician age. The particles of clastic rocks were found to consist of shale, micaceous quartzite, calcareous quartzite, limestone or dolomite, slate and flint. The most abundant were found to be quartzite, slate and shale.

Dale recorded the occurrence of graptolites of the Normanskill horizon from the shales interbedded in the Hudson grits.

Like the white beds, the grit beds of the Normanskill shale come to the surface on the Schuylerville quadrangle in two well-circumscribed areas. The grit ledges on this map are denoted by the brown symbol and are crowded in the region west and north of Quaker Springs and about Willard mountain. The former region is one of extremely rough topography, owing to the many broken edges of the grit beds in the closed synclines and anticlines. It is for this reason locally known as "The rocky tucks" and was formerly the site of considerable quarrying for sills and building stone. The ledges are especially well seen in the neighborhood of Quaker Springs. The interbedded shale is but rarely seen, since it usually has weathered back too far and is covered by drift. In one place, at least, we found graptolites of Normanskill type in the interbedded shale. The grit itself is barren of fossils, a few joints of crinoid stems being the only traces of fossils observed.

The belt of grit ledges ends rather abruptly about a mile south of Gates, or 2 miles south of the north bend of Fish creek, not to reappear farther north on the quadrangle.

The second region of grit outcrops is the Willard mountain ridge. As we noted before, the top of this very prominent ridge is formed by the white-weathering cherty beds; the flanks consist, however, of the Normanskill grit. The grit ledges appear very prominently along the lower road west of the mountain. They form considerable cliffs on the northwest side of the Willard ridge and are observable in outcrops and cliffs along the road

skirting the eastern foot of the mountain. This belt also terminates abruptly against the Georgian rocks of Louse hill, which have overridden its northern continuation in the over-thrust movement.

The boundaries between the grit zone, shale zone and white-chert bed zone are not sharply delimited, and in one place all three were found to alternate in typical beds several times in a thickness of 17 feet. As the coarse clastic material in the grit indicates, shallow marine conditions prevailed at times during the deposition of the beds and the supply of siliceous and argillaceous mud changed at times very rapidly.

The true stratigraphic relation of the shales, white-weathering beds and grit, owing to the intensely folded and faulted condition of the region, is nowhere shown conclusively. Dale in 1899 (chart facing page 178) gave the following succession in descending order: *Ig* Hudson grits, *Hw* Hudson white beds, *G* Hudson shales; placing the grits on top of the series. In 1904 (page 37) however, he published the following table showing the Hudson formation as exposed in Rensselaer county and the northeastern part of Columbia county, N. Y.:

DESCRIPTION OF STRATA	FAUNA	ESTIMATED THICKNESS IN FEET
1 Black shale with arenaceous limestone (Ruedemann's stations 24-26)	<i>Diplograptus amplexicaulis</i>	} 1200-2500?
2 Black and gray shale with interbedded grit	<i>Normanskill graptolite fauna</i>	
3 Similar shale with limestone and limestone conglomerate	<i>Trenton fauna in limestone and cement of conglomerate</i>	
4 Black, siliceous, white-weathering, cherty-looking shale		
5 Reddish, purplish, greenish shale with small quartzite bands		

Number 1 are the beds here described as the Snake Hill formation, and no. 3 those here referred to the Rysedorph Hill conglomerate, and placed now, on faunal evidence, above or near the top of the Normanskill beds; while no. 5, the colored shales, are not exposed, if present, on the Schuylerville quadrangle. It will be seen that here the grits are also placed above the white beds, while the dark shales are not recognized as a separate subdivision.

It is stated in a footnote that "the vertical relations of the colored shale and the black siliceous shale to each other and to the black and gray shale with Normanskill graptolites are not clear. They are all intimately associated." The same condition prevails farther north in the Schuylerville quadrangle. The facts which are here available for the discussion of the succession of the three divisions are, first, the arrangement in belts from west to east, and second, the structure of Willard mountain. The arrangement of the belts from west to east, with the grits as the westernmost part and the white beds following, would suggest that the grits are the youngest division, since they are nearest to the overlying Snake Hill beds. We have found in general in the shale belt, where larger faults or folds interfere, that the westernmost beds of the same zone are frequently the younger. On the other hand, the Willard mountain ridge is capped by the white beds and the mass of the mountain consists of grits, which dip east on the west side and west on the east side, indicating a more or less complex synclinal structure of the mountain and a normal position of the white beds above the grits.

In weighing the evidence from the two facts, the arrangement of the belts and the Willard mountain section against each other, we incline to consider the latter as nearer the truth, for the abrupt ending of the grit belt near Fish creek proves that the boundary line between the Normanskill and the Snake Hill formations is probably not one of simple succession, but the result of overthrusting and folding, the grit belt being faulted out north of Fish creek. The position of the grit next to the Snake Hill beds is then no evidence for the stratigraphic position of the grit nearest to the Snake Hill formation. Moreover we have good reasons for believing that in the normal succession the Rysedorph Hill conglomerate is located high up in the Normanskill. Its absence near the areal boundary on the quadrangle between the two is then further evidence of the diastrophic rather than stratigraphic character of that line.

We infer from a remark of Dale's¹ that he would have placed

¹ 1899, p. 294. Dale states: "The presence near the base of the Ordovician of a mass of grit containing fragments of slate, limestone and quartzite * * * points plainly to some unconformity at that time. The chief objection to inferring from the particles of clastic rocks in the grits, an unconformity between the Cambrian and Ordovician, is that these grits do not always occur at the contact with undoubted Cambrian rocks."

the grit at the base were it not for the fact that it is not always in contact with the Georgian. But this fact, since we now know that the Georgian and the Ordovician are in many, or all, places separated by an overthrust plane, is no longer of decisive value. On *a priori* ground, since there is an important unconformity in the slate region between the Lower Cambrian Georgian rocks and the overlying Ordovician beds, marking a long period of emergence and erosion, we should expect the Ordovician series to begin with the coarse grits, these being followed by the fine siliceous muds that produced the white beds, and the latter again by the argillaceous muds that become the dark graptolite shales. This succession agrees with the Willard mountain section and appears to us the true one.

Another question which can not be satisfactorily answered is that of the thickness of the Normanskill formation and of its divisions in this region. Dale, in the above-mentioned table, assigns the "Hudson shales" a thickness of 50+ feet; the "Hudson white beds" 400 feet or less and to the "Hudson grits" 500+ feet; and in a later paper (1904, page 37) the "Hudson formation" of Rensselaer county (including the Snake Hill beds and colored shales) is estimated at 1200 to 2500? feet. A former estimate for the Hudson formation on the east side of the Hudson river by Walcott (1890, page 346) had been 5000 feet. This, as well as Ashburner's estimate of 3500 feet for the Altamont well, are considered by Dale as too high, who holds that "in a region of such moderate relief a mass of beds 2500 feet thick,¹ thrown into small, close and mostly overturned folds, would account for such a rock surface as that depicted in that portion of the map which lies west of the Taconic range." While we agree with Dale in this latter view, we yet consider his estimates as giving the minimal estimates, rather than the maximal ones, for where the succession of faunules permitted the exclusion of the repetition of beds as a factor in increasing the apparent thickness of the formations, considerably greater thicknesses were obtained by the writer. In the case of the Deep Kill graptolite shales of Beekmantown age, for instance, the faunal zones indicate a thickness of the formation of from 200 to 300 feet, while Dale observed not more than 50 feet of this formation in any one place. It is true that Ashburner's measurement of 3500 feet in the Altamont well is not applicable to this shale region, because the shales at Altamont belong in another

¹ Dale's estimate of the combined thickness of the Lower Cambrian and Lower Silurian in the slate belt.

basin and consist of Canajoharie, Schenectady and Indian Ladder shales. Nor can the great thickness of shales, passed in well-borings in the shale region itself, be considered as demonstrating a great thickness of the shales. In a well at Mechanicville, for instance, 1400 feet of shale were passed without reaching the bottom of the formation; since the shales there, however, are not only dipping at an average angle of about 70° , but also repeated in overturned folds, the thickness of the shale in the well is clearly no indication of a corresponding thickness of the shale beds.

That the possibility exists of great thickness of these shales in this region, however, is shown by the Canajoharie and Schenectady shales in the closely adjoining basin to the west, which were found to reach together more than 3000 feet in thickness.

On the western side of Willard mountain there are exposed about 400 feet of grits, probably without repetition of the beds, a thickness which fairly agrees with Dale's estimate. We would estimate as follows:

Grit.	500+ feet
White beds.	400± feet
Shale.	100± feet

Fauna of the Normanskill beds. Faunules, mainly of graptolites, have been found in many places in the Normanskill belt on the Schuylerville quadrangle. We cite here only the more important occurrences which show the position of the grit, the white beds and shales in the Normanskill formation.

An outcrop of deep black shale, interbedded in the *grit* of the Rocky tucks, about 2 miles north of Quaker Springs, contained:

Corynoides gracilis Hopkinson
Didymograptus subtenuis (Hall)
Leptograptus sp.
Dicranograptus ramosus Hall
Climacograptus parvus Hall
C. scharenbergi Lapworth
Diplograptus cf. *acutus* Lapworth

This is a typical Normanskill association of species.

A six-foot bed of compact black *cherty rock* in a brook just above Coveville contained:

Dicranograptus ramosus Hall
Climacograptus parvus Hall

C. modestus Ruedemann

Retiograpthus geinitzianus Hall

The black shale in a small railroad cut north of the Schuylerville station proved quite fossiliferous.¹ It has furnished:

Corynoides gracilis Hopkinson

Didymograptus subtenuis (Hall)

Leptograptus flaccidus mut. trentonensis Rued.

Dicranograptus ramosus Hall

Climacograptus bicornis Hall

C. parvus Hall

Graptospongia pusilla Ruedemann²

Leptobolus walcotti Ruedemann

This shale with its characteristic Normanskill fauna is intercalated in the white beds.

The shale and white beds abutting at the north and south against the Northumberland plug were found to contain *Didymograptus sagittarius*, showing that the plug is undoubtedly surrounded by Normanskill shale.

The black cherty band at Clarke's Mills mentioned above contains *Climacograptus parvus*, which also is restricted to the Normanskill shale.

Black shale, associated in the Willard mountain region with the white beds, contains:

Corynoides gracilis Hopkinson

Didymograptus sagitticaulis Gurley

Dicranograptus ramosus Hall

Dicellograptus sextans Hall

Cryptograptus tricornis (Carruthers)

and the white beds capping this mountain are hence also undoubtedly of Normanskill age.

A good Normanskill fauna was also collected in shales associated with the six-foot bed of chert on the east shore of Saratoga lake, namely:

Corynoides gracilis Hopkinson

Dicranograptus ramosus Hall

¹ This locality was pointed out to the writer years ago by Prof. J. B. Woodworth.

² The originals of this sponge (described in N. Y. State Mus. Mem. 11, 1908, p. 485) came from this locality.

D. contortus *Ruedemann*

Climacograptus bicornis *Hall*

C. parvus *Hall*

C. putillus var. *eximius* *Ruedemann*

Glossograptus ciliatus *Emmons*

Lasiograptus bimucronatus (*Hall*)

Leptobolus *sp.*

Correlation. The writer, finding the Normanskill shale below beds with *Diplograptus amplexicaulis*, had inferred (1901) that it was at least as old or older than middle Trenton and correlated it with the middle and lower Trenton. It appears now from evidence obtained by Ulrich (op. cit. page 512) in the Athens trough, that the formation is still older and corresponds in age to the upper Chazy. But the Rysedorph Hill conglomerate of Black River age is intercalated in the Normanskill shale in a number of localities, some of which have been cited above (page 82) and to which may be added the fossiliferous exposure of the conglomerate in the big cut of the Boston & Albany Railroad south of Rensselaer.

These militating observations of the Chazy age of the Normanskill shale and of the intercalation of the Rysedorph Hill conglomerate of Black River age, appear to find their solution from observations made lately by the writer, leading to the inference that the Normanskill shale comprises two divisions or formations, the lower of which is of Chazy age and the upper of Black River age and possibly somewhat younger. This upper formation contains the Rysedorph Hill conglomerate. The inference of the subdivision of the Normanskill shale is based partly upon an unmistakable distinction in the graptolite faunules, indicating an older and a later horizon — to be worked out more fully when favorable sections present themselves — and partly upon the observation of traces of other fossils than graptolites and younger than Chazyan in age in the upper Normanskill shale.

SNAKE HILL BEDS

The Snake Hill formation occupies the southeast corner of the Saratoga quadrangle, from Ballston Spa and the Kayaderosseras creek to Saratoga lake. It crosses the Schuylerville quadrangle diagonally as a belt 4 to 5 miles wide, and a second eastern belt follows the Hudson river and unites with the western belt north of the Batten kill. These belts are segments of a greater belt that extends from Pennsylvania through southern New York along the

Hudson past Albany and Cohoes on to the Saratoga and Schuylerville quadrangles.

The formation was first distinguished by the writer from the "Hudson River formation" in the neighborhood of Albany (1901) and partly referred to as middle Trenton shale and partly as Utica shale and later correlated with the Magog shale of Canada. Mainly on account of the large and distinguishing faunas obtained around Albany, Green Island and Cohoes, and especially at Snake hill on the shore of Saratoga lake, the formation has recently (1912) been considered as a separate formation by the writer and named the *Snake Hill beds* from the most fossiliferous outcrop.

Lithologically, the formation is similar to the Normanskill beds, but it lacks the strong development of the grits and white beds as distinct divisions, though both are present in thinner intercalations. Besides it possesses a conglomerate with characters peculiar to itself. The preponderating portions of the formation, however, are dark gray to black, bluish and greenish gray argillaceous shales which are difficult of separation from the Normanskill shales, save by the inclosed faunas.

The argillaceous shales prevail so much in the Snake Hill formation that we have not observed in the belt in Albany county any grits and are aware of only one outcrop there with cherty-looking silicious shales. Also on the Schuylerville quadrangle the conglomerate, the grit and the cherty beds have been observed each only in a couple of outcrops, the rest all being soft shale. Thus, the large area in the northeast corner of the sheet, north of Moses kill, which has a rocky surface throughout, consists entirely of shale. The uniform composition of the formation of shale is also well shown in the new barge canal about Fort Miller, where half a mile of rock exposure exhibits nothing but dark gray shales.

Black, carbonaceous, graptolitiferous bands or seams are more frequently found than in the Normanskill shale, but they contain a much impoverished graptolite fauna as compared with that of the Normanskill formation. On the other hand, small lamelli-branches, gastropods, brachiopods and trilobites are frequently seen in the shale, while but traces of such have as yet been observed in the Normanskill shale.

The dark shales contain not infrequently thin, sandy bands and still oftener intercalations of sandy limestones and also gray crystalline limestone, reaching half a foot in thickness. These bands frequently contain a faunule of brachiopods, crinoid joints, etc., and

they have furnished the great number of fossils, other than graptolites, recorded by the writer in Bulletin 42. Frequently concretions of both limestone and clay are found scattered or more or less obscurely arranged in layers.

Owing to the extreme pliability of the argillaceous shales and the lack of strengthening intercalations of grits etc., the Snake Hill beds are, as a rule, intricately contorted and crumpled and cut by cleavage planes and smoothed slip planes, until they have the character of the shales which were termed by the geologists of the first survey "glazed" and "semimetamorphic" shales. These shales so designated were Snake Hill shales of the Hudson valley. Yet, localities have been observed, as at the west shore of Saratoga lake, where these shales were distinctly slaty, and near Argyle, just beyond the edge of the sheet, they have been quarried for slate.

At Snake hill — a picturesque high promontory on the east side of Saratoga lake and an old landmark, suspected by many of the settlers of the region of being an "old volcano"—the formation has a different character, the shales containing here compact grit and conglomerate beds 1 to 4 feet thick, consisting of coarse sandstone with silicious and argillaceous cement and many pebbles, up to 1 inch in diameter, well rounded and consisting of shale, black limestone, cherty "white bed" and milky quartz. While the grit and conglomerate beds are bent into recumbent, nearly flat folds, the intercalated shales are intensely crumpled. There also occur thinner beds of gray, crystalline, often sandy limestone. In following the grit beds along the shore it is seen that they are not very extensive, very irregular in thickness and sometimes replaced in a short distance by shale. All the rocks of this locality, the shales, the limestone bands, the grits and the conglomerates, are fossiliferous and besides a few graptolites furnish cystids, crinoids, brachiopods, gastropods, pelecypods and trilobites. In the shore cliffs of the lake a mile north of Snake hill, lamellibranchs and gastropods occur in association with some of the characteristic graptolites of the formation, and in the little disturbed beds of the west shore the graptolites were found in fine preservation in a number of places.

Only one other outcrop of the conglomerate bed was observed, 6 miles northeast of Snake hill. The bed may therefore be lenticular and of but local extent. Intercalations of silicious shales weathering whitish and of sandstone beds were observed in the section exposed along the road leading southeast from Gansevoort

to the Hudson river. These were, however, in every case insignificant in thickness and less characteristic in development than those of the Normanskill formation, the thickest sandstone bed measuring but 3 feet.

The Snake hill locality has furnished the following fauna:

Graptolites

- Dicranograptus nicholsoni* *Hopkinson*
- Diplograptus* (Mesogr.) *putillus* *Hall*
- Corynoides* *sp.*

Crinoidea

- Glyptocrinus* *sp.*
- Heterocrinus?* *gracilis* *Hall*
- Cremacrinus* *sp.*
- Carabocrinus* *cf. radiatus* *Billings*

Cystoidea

- Edrioaster saratogensis* *Rued.*

Bryozoa

- Paleschara ulrichi* *Rued.*

Brachiopoda

- Schizocrania filosa* (*Hall*)
- Plectambonites sericeus typus* (*Sowerby*)
- Plectorthis* *cf. whitfieldi* (*Winchell*)
- Dalmanella testudinaria* (*Dalman*)
- Plaesiomys retrorsa* *auct.*
- Rafinesquina alternata* (*Emmons*)
- Clitambonites americanus* (*Whitfield*)
- Parastrophia hemiplicata* *Hall*
- Zygospira recurvirostris* (*Hall*)

Pelecypoda

- Whiteavesia cincta* *Rued.*
- W. cumingsi* *Rued.*
- Orthodesma?* *subcarinatum* *Rued.*
- Whitella elongata* *Rued.*
- Clidophorus ventricosus* *Rued.*
- C. foerstei* *Rued.*
- Ctenodonta levata* (*Hall*)
- C. declivis* *Rued.*
- C. prosseri* *Rued.*
- C. radiata* *Rued.*
- C. recta* *Rued.*
- C. subcuneata* *Rued.*

Lyrodesma schucherti Rued.

Solenomya? insperata Rued.

Cuneamya acutifrons Ulrich

Gastropoda

Archinacella orbiculata (Hall)

Cyclonema montrealense Billings

C. cushingi Rued.

Clathrospira subconica Hall

Pterotheca cf. canaliculata (Hall)

Crustacea

Eoharpes ottawensis Billings

Trinucleus concentricus (Eaton)

Proëtus undulostriatus (Hall)

Calymmene senaria Conrad

Lepidocoleus jamesi H. & W.

Ctenobolbina subrotunda Rued.

Technophorus cancellatus Rued.

Other localities which deserve notice are:

1 The shore 1 to 2 miles north of Snake hill, where the shales contain:

Dicranograptus nicholsoni Hopkinson, abundant

Diplograptus amplexicaulis var. pertenuis Rued.

D. (Mesograptus) putillus Hall

Archinacella orbiculata (Hall)

Leptobolus sp.

2 West shore of lake (Edgewater Park, Rileys etc.):

Dicranograptus nicholsoni Hopkinson

Glossograptus quadrimucronatus mut. pertenuis Rued.

Diplograptus amplexicaulis Hall

D. amplexicaulis var. pertenuis Rued.

D. (Mesograptus) putillus Hall

Climacograptus spiniferus Rued.

3 A thin sandstone band in the shale at the foot of the hills east of Moses kill contains:

Schizocrinus cf. nodosus Hall (joints)

Dalmanella testudinaria (Dalman)

Plectambonites sericeus (Sowerby)

Rafinesquina alternata (Emmons)

Cyclora cf. minuta Hall

Spyroceras bilineatum (Hall)

Proëtus undulostriatus (Hall)

4 A similar faunule was obtained in a thin limestone band, consisting entirely of shells, intercalated in the shale at the bank of the Hudson river, 2 miles above the mouth of the Snook kill. Here were found:

Glyptocrinus cf. decadactylus Hall (joints)

Corynoides gracilis Hopkinson

Lasiograptus eucharis (Hall)

Plectambonites sericeus (Sowerby)

Dalmanella testudinaria (Dalman)

Trinucleus concentricus (Eaton)

Thin limestone bands consisting of shells of *Dalmanella* and crinoid joints were met with in a number of localities.

5 The black shale brought out of the canal at Fort Miller contains:

Diplograptus amplexicaulis var. *pertenuis* Rued.

Diplograptus putillus Rued.

Lasiograptus eucharis Hall

Leptobolus cf. insignis Hall

Sandy and calcareous bands

Joints of *Schizocrinus nodosus* Hall

Dalmanella testudinaria (Dalman)

The outcrop of black shale below the dam in the Batten kill at Crowe's $1\frac{3}{4}$ of a mile above Clarke's Mills, contains:

Corynoides gracilis Hopkinson

Diplograptus (*Mesograptus*) *putillus* Hall var.

Diplograptus amplexicaulis Hall

and the shale below Middle Falls

Corynoides calicularis Nicholson

Diplograptus (*Mesograptus*) *puillus* Hall var.

Worms (*cf. Pontobdellopsis cometa* Rued.)

The localities between the Hudson river and Willard mountain and on the other side of the river have afforded:

Diplograptus amplexicaulis Hall

Diplograptus (*Mesogr.*) *putillus* Hall

Lasiograptus eucharis (Hall)

and abundant worms (*cf. Pontobdellopsis*)

The fossils which are most frequently met with in the shales are: the graptolites *Corynoides gracilis*, *Dicranograptus nicholsoni*, *Diplograptus amplexicaulis*, *D. amplexicaulis* var. *pertenuis*, *Climacograptus spiniferus*, and the little gastropod *Archinacella orbiculata* and little lamellibranchs of the genera *Clidophorus* and *Ctenodonta*, while the limestone and grit bands contain the brachiopods *Dalmanella testudinaria*, *Plectambonites sericeus*, fragments of *Rafinesquina* and crinoid joints. Rarely a larger fauna of mollusks and trilobites occurs, as at Snake hill, and some places in Albany county. Also worms similar to those described from the Canajoharie shale are frequently seen.

The frequent occurrence of *Dicranograptus nicholsoni* type which is not found in the Normanskill shale, appears to us especially characteristic of this formation, especially about Saratoga lake, while *Lasiograptus eucharis*, which is extremely common in the Canajoharie shale, is here less frequently met with.

Correlation. From the fauna of the Snake Hill beds it can be inferred that the formation is of early Trenton age and roughly corresponds to the lower and perhaps part of the middle Trenton. It probably rests upon the upper division of the Normanskill shale and is the youngest of the rock formations of the Levis basin that by overthrusting and intensive folding have been pushed westward into contact with the formations of the Mohawk-Champlain basin (see diagram, page 140).

STRUCTURAL GEOLOGY OF THE SHALE BELT

BY R. RUEDEMANN

The principal structural feature of the shale belt of the two quadrangles finds its expression in the contrast of the flat-lying or but slightly dipping shales of the western trough and the intensely folded and crumpled condition of all the rocks east of this belt.

The boundary line between the folded and flat shale areas coincides very nearly with that between the Canajoharie and Snake Hill shales, not only on the two quadrangles here described, but in the entire inner lowland extending from the Helderberg cuesta to the Adirondacks and then into the Champlain basin and presumably farther north. It does not coincide exactly because in some

regions the folding has transgressed a few miles into the Canajoharie shale area while in others some western marginal cakes of the Snake Hill beds have been left only shattered by fault slips. Thus in Albany county the Canajoharie shale belt striking along the Hudson river has become, partly at least, involved in the folding, while on the Saratoga sheet the Snake Hill shales west of Saratoga lake are only tilted and broken. The boundary between the folded and unfolded areas follows thus on the Schuylerville quadrangle the longer axis of Saratoga lake, being probably in part responsible for the existence of this basin in that place. It thence continues northwest passing west of Kendricks hill where folded Snake Hill shales are exposed. The folded area may also include the last outcrops of Canajoharie shale on the Snook kill below Gansevoort, the shale being there in steeply eastward dipping position.

In general, however, the boundary of the folded and unfolded regions coincides so closely with the Canajoharie-Snake Hill boundary that the proposition of the folding and shoving of the eastern series of shales upon and against the western is well supported by this fact. The crumpling up of a narrow belt of Canajoharie shale in front of the folded area in Albany county on one hand and the shoving westward of a cake of Snake Hill beds without folding (but with much slipping, see below page 103) in Saratoga county on the other hand, both result from the varying resistance offered the oncoming waves of pressure and of folds from the east, through the thickness of the opposing strata and the weight of their covering formations. It appears from the fact that some of the outcrops on the southeast shore of Saratoga lake (on the Cohoes quadrangle) show a great number of closely arranged thrust planes, all rising slightly to the west, that the pushing force in this more or less unfolded western cake was largely spent in overthrusting, this action taking place near the surface under little or no cover.

We have shown before that the Canajoharie and Snake Hill beds belong to different series of rocks, deposited in different basins. Of these the Canajoharie shales have changed their position on the whole only vertically through normal faulting, while the folded shales must have been transported for some distance subhorizontally to come to lie in contact with and partly above the western series. This transportation took place both by folding and overthrust faulting. There is little doubt that the

western series has been overridden by the rolling and slipping mass of the eastern shales and grits to an extent at present unknown. We have in the sections extended the Canajoharie shale and the underlying limestones and sandstones to the eastern hill region, because from the thickness of these formations at Saratoga it is sure that they continue for a considerable distance eastward under the crumpled shales. Quite probably they descend gradually eastward under a subhorizontal thrust plane, partly by step faults, such as bring the limestones at Saratoga Springs down to the level of the village (see diagram on left).

The Canajoharie shales of the western belt exhibit but gentle dips in most outcrops. In the region of the Glowegee the dip is to the west toward the fault and to the southwest, while about Saratoga and on the Schuylerville quadrangle it is mostly to the east and southeast, usually less than 5° . Exceptions are the outcrops on the upper Snook kill, at the foot of Mt McGregor, where the dip is on the average 50° and as high as 65° , owing to the nearness of the McGregor fault line that separates the shale and Precambrian rocks. At Gansevoort the shale is already much disturbed by slipping and folding, but in general dips steeply southwest, while at Fort Edward, a few miles beyond the limits of the quadrangle, the dip is about 12° to southeast. Both at Gansevoort and Fort Edward a great number of small slips occur, and the varying dip to northwest and southeast indicates that the shale belt is broken into many tilted blocks by faults more or less parallel with the master faults, that is, faults running in southwest-northeast direction. None of these larger faults has been directly observed in the shale. Nevertheless their presence can be directly inferred in several places, as at Rock City Falls and half way between North Wilton and Saratoga Springs, where faults pass from the limestones southwestward into the shales. The fault separating Canajoharie and Snake Hill beds at Ballston may also belong in this class.

Besides these supposed larger faults, a multitude of small slip faults transect the shale. All of these strike northeast, more or less parallel to the master faults, dip slightly to the east and the upthrow side is on the east, all of these faults being of the nature of small overthrusts. The throw is everywhere small, being but a few feet or in some cases only a few inches. Three of them were observed in the lower gorge of the Kayaderosseras, others in the Snook kill near Gansevoort. The best instances of these

small overthrusts in the Canajoharie shale occur at the dam at Fort Edward. Here the shale is already somewhat contorted and folds that are inverted to the northwest are exposed. The entire mass of rock is, however, cut by a great number of slip or overthrust faults, dipping southeast at 12° to 14° . The throw is always very small and the thicker and harder beds in the shale are seen to be broken by the slip planes, the upper part being thrust forward a little over the lower, the whole suggesting surface thrusts. These small slips and folds in the eastern margin of the flat shales of the western basin were produced either below the overriding eastern rock masses or in front of them. The step faults prevail therefore in the western part of the belt and the slip faults in the eastern.

At Hudson Falls, a few miles north of the Schuylerville quadrangle, the Canajoharie shale, in being pushed northwestward before the eastern rock masses, appears to have encountered some resistant body which twisted the shales; they are here shattered and filled with a great profusion of calcite veins. It seems as if the spur of limestones and dolomites that protrudes through the shales a mile farther west, at Glens Falls, had been this resistant boss.

Folded area. The structure of the folded area is of the most complex character imaginable. It will be discussed in two parts, (1) the structure of the Ordovician shale in the Hudson River plain, (2) the structure of the Georgian rocks and associated Ordovician formations in the eastern (Greenwich) hill region.

The shale belt of the Hudson River plain in the folded area consists principally of the Normanskill shale in the middle and the Snake Hill shale on both sides. This entire mass is uniformly thrown into a mass of closely packed, small closed folds that are asymmetric and uniformly overturned or inverted to the west, so that on the surface and in sections where the tops of the anticlines are eroded away, the entire mass has an isoclinal structure, all beds dipping to the east with varying angles, averaging about 70° . This is especially true where only shales are involved. Where, however, more resistant beds, especially the grit beds, are present, these appear to be folded into less compact or closed folds, and they are liable to form broad open folds in one place and recumbent ones in places near by, as on Snake hill. In the Rocky tucks each leg of the inverted anticline forms, as a rule, a ridge by itself, the roof or top of the anticline being broken out. These

small anticlines are mostly of short length, pitching often considerably at the north and south ends. They cause the grit and chert ridges to rise for a short distance above the surface to soon disappear again.

It is probable that also in the Saratoga plain in places a number of smaller anticlines and synclines are combined into larger anticlinoria and synclinoria. At least the presence of a multitude of small grit anticlines in an elliptic space, as in the Rocky tucks, would suggest the probability of such a more complex structure. There is little doubt that anticlinoria and synclinoria exist farther east,¹ where the pushing force was greater and the rocks more resistant, but in this western shale belt the entire crumpled, minutely and often irregularly folded mass has the appearance of a rolling and slipping mass, not strong enough to be thrown into folds of mountain-making magnitude. Yet we find already close to the east, in the hill region, as in Willard mountain, clear evidence of a syncline on such a larger scale.

These folded and crumpled shales are further cut by a very regular cleavage and by faults. The cleavage is ever present in the folded shale region; the cleavage plane dips nearly always to the east, similar to the bedding planes, most frequently intersecting the latter at an acute angle.

While the contorted appearance of the shales in consequence of the many folds often gives the whole mass the appearance of having yielded to the pushing force by simply crumpling up, there is also everywhere evidence of a slipping of the rocks along innumerable slip planes or small thrust faults. We have already mentioned their presence in the eastern portion of the little disturbed Canajoharie shales. In the folded area, however, we have met them everywhere. In the good east-west section, for instance, which the Batten kill furnishes at Clark Mills, a whole series of such faults, about 10 to 20 feet distant from each other, were observed in the north wall and traced across the river bed. They all rise toward the west at angles varying from 20° to 45° and many are made conspicuous by calcite veins. The throw is always small, but the upthrow side is always pushed a little to the west. On the west shore of Saratoga lake where the shale lies in places nearly flat, one overthrust plane was observed that was nearly horizontal; in the cliffs of the southwest shore of the

¹ Dale p. e. has described Mt Greylock as a synclitorium.

same lake (on the Schenectady quadrangle) many such overthrust faults were observed; in one place three above each other. They all dip southeast, mostly at an angle of about 25° . Others were observed in the bed of Fish creek at Victory Mills and in road metal pits. In one place, a road metal pit east of Saratoga lake, the slickensides upon the thrust planes, and especially the direction of the slickenside scales, left no doubt that the upthrow side had moved from east to west upon that plane. Some of these overthrust faults have clearly resulted from overturned folds (fold thrusts). The upper leg is seen in such cases to have been pushed westward beyond the lower. Some instructive examples of this were seen about Saratoga lake, especially on Snake hill. Most of these small faults run with the general strike (north-northeast direction) of the beds or are strike faults; some were, however, observed which cut the beds obliquely, as one at Victory Mills, striking N. 60° E. These deviations from the general north-northeast direction are probably connected with local irregularities in the general trend of the folds.

While the throw of each of these overthrust faults is but small, their accumulative effect, going from west to east, owing to their great number and uniform direction of throw, must be quite large. If we assume a throw of 6 inches for each fault and that they are 20 feet apart, we obtain for the belt measured from the foot of Willard mountain normal to the strike, with a width of 10 miles, a compound throw of 1320 feet. The effect of this accumulative throw would be to bring progressively older beds to the surface of the Saratoga plain as one goes east. It is therefore possible that the position of the Normanskill belts to the east of the Snake Hill belts is largely due to this effect of the small numerous overthrust faults which might be termed "*progressive overthrusts*."

The interesting observations of Woodworth¹ have shown that faulting of "repetitive" character is still going on in the shale belts to the south of the Schuylerville quadrangle and possibly also in the latter. These small faults have also the same northeast strike and where observed, raise the eastern part above the west-

¹ Woodworth, J. B. Postglacial Faults of Eastern New York. N. Y. State Mus. Bul. 107, p. 5, 1907.

ern, and may therefore be a continuation to the present day of the "progressive overthrusting" here described.¹

There is, however, also evidence of possible larger faults, both normal and overthrust, in the folded shales of the Saratoga plain. One larger fault is directly observable at Ballston Spa, separating the Canajoharie shale and Snake Hill beds. This fault is traceable southward through the Ballston lake depression toward the Mohawk river. Its presence is shown by the steep eastward dip of the Snake Hill beds, which rapidly decreases as one goes east, the part of the Snake Hill belt between Ballston Spa and the lake being but little disturbed by crumpling. From present evidence we infer that an important thrust plane separates the Snake Hill and associated now intensely crumpled formations of the eastern basin from the relatively undisturbed Canajoharie shales, along this fault line northeastward beyond the limits of the map. This fault, which is probably a nearly horizontal thrust fault (see diagram), is of the character of a "scission" fault or "charriage." The eastern formations have been pushed westward over this plane for an unknown, but probably considerable, distance. If our conclusion that the Rysedorph Hill conglomerate properly comes in the upper part of the Normanskill shale is correct, then its absence near the boundary line of the two on the Schuylerville quadrangle would also indicate that this line is not one of normal stratigraphic succession, but of diastrophism or movement of the earth crust. As we have shown above, the entire shale belt is transected by a great number of slips or thrusts of small throw, which combined might be competent to bring up the older shales in overlying position to the younger ones; they would, however, not throw the Rysedorph Hill conglomerate out of its supposed normal position near the top of the Normanskill beds.

Whatever the character of the contact along the western edges of the Normanskill areas may be, it seems clear that it is in the nature of an overthrust, either a single large overthrust or a

¹ Woodworth (op. cit. p. 26) is inclined to explain these small faults as step faults with a downthrow to the northwest, which would produce the same effect as an overthrust from the east, and to consider them as part of a tilting of the land in and about the New England district, since the retreat of the Wisconsin sheet, or as resulting from the lifting out of the cores of synclines through lateral pressure from the east. Since the synclines, as a rule, are overturned to the west and compressed into close folds in the shale district, it is improbable that the forcing out of the core of the synclines could be responsible for the numerous small overthrusts observed by us.

number of small ones of the character of progressive overthrusts. In the western Normanskill area this is suggested by the pinching out of the grit belt, as stated before, against the western boundary of the area. The line bounding the Willard mountain area of Normanskill rocks on the west is to all appearances of the same character, for this would explain in part that the older Normanskill rocks project here more than 1000 feet above the younger Snake Hill beds adjoining them to the west, and that we find structures, as the cross fold in the southeast corner of the sheet, cut off by that line.

If the eastern Normanskill belt is also overthrust westward, it would seem to have been not only overthrust, but also thrown into the high mountain folds of Willard mountain before the oncoming of the Georgian overthrust waves, for the latter were clearly turned aside by this projecting mass, as shown by the curving strike of the Georgian rocks northeast of Willard mountain. That it still in this late time projects so boldly is of course mainly due to the great hardness of the grit and especially of the white-weathering chert beds which form its backbone.

As far as this relatively small area indicates, we have here a series of successive overthrust masses, producing the intricate structure which in various parts of Europe is known as "Schuppenstruktur," the separate Schuppen being pushed over each other like scales (Schuppen).

While the prevailing material of the rocks that have been overthrust consists of shales, there are, it appears to us, sufficient masses of solid, hard grit and chert beds in the Normanskill and Snake Hill shales and of limestone and quartzite beds in the Georgian rocks to have transmitted the stress to the shales. Also the compact Bald Mountain limestone and dolomite must have been important agents in the development of the overthrusts. In the Bald mountain section (see page 109 and sections and diagrams in pocket) the limestone is seen to be bounded by overthrust planes from the shales above and below, showing that the shear followed in some places the bedding planes between the limestone and shale, thus separating the two. It is possible that the successive overthrusting took place similarly as suggested by Bailey Willis¹ for the Alpine structure, although we have been led to infer from our observa-

¹ Bailey Willis. Thrusts and Recumbent Folds, a Suggestion Bearing on Alpine Structure. *Science*, 25:1010.

tions that the uppermost thrust plane, that of the Georgian, is the youngest, while Mr Willis considers the lowest, the great major thrust C of his diagram as the youngest.

The appearance of a narrow belt of Schaghticoke shale between Schuylerville and Thomson is evidence of a fault in that section, for since the Schaghticoke is separated by the considerable thickness of Deep Kill shales from the Normanskill shale and these are absent at Schuylerville,¹ a single anticline would not explain the occurrence. It is either a mass, entirely separated from its roots in the contorted and crumpled shale mass, or a small fault block thrust through the other shales. Close by is the "Northumberland volcanic plug," which also is cut by slickensided planes striking in the general direction of the faults of the area; and which, according to Professor Cushing's investigations, may be a similar small block, torn off its main mass and carried forward with the shale masses of the "Decke."²

The structure of the Greenwich plateau. The Greenwich plateau enters the Schuylerville quadrangle from the east with a belt only 1 to 2 miles wide. We have to distinguish two structures in the part of the plateau with which we are concerned, namely, the Willard Mountain syncline and the Georgian overthrust mass.

1 *Willard Mountain syncline.* We have mentioned above that the imposing and historic Willard mountain, which rises boldly more than 1200 feet above the bed of the Hudson river, presents the structure of a syncline, much larger and more open than the synclines observed in the shales of the Saratoga plain. This open structure is obviously due to the presence of a great amount of grit and silicious, cherty shale in the strata folded there. At the northeast end the strike of the beds swings around from northeast to northwest, suggesting that the syncline terminates here abruptly with a well-rounded curve. At the eastern foot of the mountain a coarse conglomerate forms the crest of a small anticline.

2 *Georgian overthrust blanket.* If one wanders from the Hudson river, for instance at Thomson or Clark Mills eastward,

¹ We omit here the distant possibility that the Beekmantown beds could be absent in the series at Schuylerville, although it has been claimed that they are intermittent.

² Since "blanket" corresponds to the German "Decke" and means *a cover*, relatively thin, such as these thrust masses are, they might be called "thrust blankets." The word "sheet" would be liable to confusion. The French "carriage" is also transferable, although the meaning of the English word carriage for "that which is carried" has become archaic (Webster).

one passes in the Hudson River plain over Snake Hill shales, frequently covered by quaternary clays, until near the foot of the hills marking the edge of the Greenwich plateau. Here there is a belt of much broken and distorted Beekmantown limestone (Bald Mountain limestone) and coarse conglomerate (Rysedorph Hill conglomerate), and the hills themselves and the plateau behind them consist of the Georgian rocks. The latter, although immensely older, hold a higher level than the shales west of them. The explanation of this remarkable fact is that the Georgian has been overthrust upon the Ordovician rocks. This is most clearly shown at Bald mountain where the former quarrying of the limestone at the foot of the mountain has opened a splendid section (see plate of sections).

Bald mountain is, geologically speaking, an historical mountain. It has played a conspicuous rôle in the Taconic controversy and it is therefore proper in this place briefly to review its history. Emmons was the first to direct attention to the Bald Mountain section as being an interesting example in the relative position of the "Taconic" and "Champlainic" (Ordovician) rocks, that is, as showing the Champlainic rocks as resting unconformably on the Taconic rocks. He gave (1846, page 89) a section through Bald mountain showing the "calciferous sandstone" extending from the top of the mountain to the western foot where it is underlain by the "Taconic" black slates, which also appear on the eastern foot of the mountain. The two trilobites *Atops trilineatus* and *Elliptocephala asaphoides*, which demonstrated the actual presence of rocks older than Potsdam in the slate belt, were also cited as coming from the strata "near Bald mountain"¹ (*op. cit.*, page 63).

Walcott (*op. cit.*, page 317) has shown that the complex structural relations of Bald mountain are entirely different from what Emmons supposed them to be. He found Georgian fossils in the limestones, forming the summit of the mountain, and states: "Doctor Emmons identified this mass of strata, *d*, with the calciferous sandrock on lithologic characters, overlooking the fact that a similar rock might occur in his Taconic series." Walcott also recognized the overthrust at Bald mountain. He says: "The section of Bald mountain proves that the strata of the 'Upper

¹ Walcott (*op. cit.*, p. 326) cites them as coming from the black slate 2 miles north of Bald mountain, where Doctor Fitch found them.

Taconic' are there pushed over on to the Chazy Terrane, and that the 'Upper Taconic' is not unconformably subjacent to the latter or to the Calciferous sandrock."

The fossiliferous limestone of the downthrow block is Beekmantown; the lower, darker dolomitic beds belong to the same formation with the upper, lighter, purer limestones, being separated at Bald mountain by an inthrust wedge of shale and conglomerate. The black slates which Emmons considered as the Taconic black slates underlying the "calciferous sandrock" are the Snake Hill shales, and his conception of the structure of Bald mountain has thus become completely reversed.

The Bald mountain section is of great interest, not only in regard to the Taconic controversy and the different explanations offered for it, but especially as distinctly showing an overthrust of the Georgian rocks upon the Ordovician beds and the thrust-shattered condition of all the beds involved in the section. The photographs on plates 12-14 show the limestones much broken by thrust planes auxiliary to the master overthrust, and overlain by masses of mylonite (see page 84) upon which rest the Georgian shale and shaly limestone. There remain standing detached cliffs or blocks consisting of conglomerate and shale on the south side and in front of the quarry, which indicate the former extent of this formation, while to the southwest and west of the quarry there outcrop in several places the dark dolomites (see diagram of front of mountain, plate of sections). It thus appears as if the shales and conglomerates separate the pure limestone above and the dark dolomite below. As we have stated in another place, these two divisions both north and south of Bald mountain grade into each other and form one formation. It is therefore probable that the shales and conglomerate in front of Bald mountain form only a wedge thrust in between the limestones and dolomite.

Dale (*op. cit.*, page 293), from his elaborate investigation of the New York-Vermont slate belt, arrived at the conclusion that the overthrusting at the western margin of the Cambrian area is only local in the shale region of New York-Vermont. He says:

The striking features in all these localities, leaving out the last, are the uniformity of the dip, the great thickness of the Lower Cambrian, and the thrusting over of the latter on the Trenton. These features imply great rigidity in the beds and relief of compression through faulting. These, however, are just the features which are wanting along the slate belt. The

Cambrian beds are all in minor folds, as are certainly the several isolated Ordovician areas and the large central ramifying ones. And there is no evidence of such a great overthrust as at Burlington and Saint Albans. But Mr Walcott does find evidence of an overthrust on Bald mountain, in the town of Greenwich, in Washington county, New York, west of the slate belt. The exposures described near North Granville (page 292) also indicate reverse faulting. Yet the course of the Cambro-Ordovician boundary along the western edge of the slate belt, particularly northeast and southwest of North Granville, New York, and in Benson and Hubbardton, Vermont, and again in the townships of Hartford, Argyle, and Hebron, New York, is hardly consistent with the existence there of a great longitudinal overthrust, nor do the vertical relations of the Ordovician and Cambrian outcrops favor such a construction. If such a thrust plane separates the two formations, it must be a folded thrust plane, which is not an ordinary probability.

It would appear, therefore, that the great mid-Silurian orogenic movement which, in northern Vermont, operating upon rigid beds, found relief in a great overthrust, at the south, near the slate belt, operating upon beds which were more plastic, compressed them into minute folds. In either case the compression at the south found relief chiefly in folding, and only here and there, as about North Granville and at Bald mountain, in faulting. But evidences of faulting may be found west of the area here mapped.

In 1901 (page 555ff.) the writer explained the inverted order of the formations observed by him in the neighborhood of Albany by an overturned fold which changed into an overthrust fault, whereby the Georgian became overthrust upon the underturned wing. This view was also reached by Dale in the *Geology of the Hudson Valley between the Hoosic and the Kinderhook* (1904, page 38). He states: "That the relations on the west side of the Cambrian belt are not only those of unconformable deposition but of more or less continuous overthrust is rendered somewhat probable from the situation of the overthrust near Schodack Landing and of that at Bald mountain in Greenwich, 47 miles north-northeast of the former, as well as from the general direction of the Cambro-Hudson boundary between them. . . . For these reasons it is assumed that in consequence of a westwardly overturned fold, which is frequently ruptured, the Lower Cambrian here usually overlies the Hudson, that is, the Trenton or middle part of the Ordovician."

The subsequent work of the writer seems to indicate that this view as to the origin of the overthrust of the western margin in which he and Dale agree, is the one nearest the truth. We see possible evidence of this hypothesis in the belt of Bald Mountain limestone of Beekmantown age, outcropping below the Georgian

along the western edge of the Greenwich plateau. This limestone, which, on account of its Beekmantown age, now recognized, is to be considered as underlying the Snake Hill shale, just below it, may indicate an inverted order below the Georgian, although there is a stronger probability that its presence is due to its having been brought along with the Georgian along the thrust plane.

Our observations along the west edge of the Cambrian area, not only on the Schuylerville quadrangle but also northward and south of it in Rensselaer and Columbia counties, have led us to the conclusion that we have there precisely that case which Dale considered as not an ordinary probability, and therefore would exclude from his working hypotheses, namely, a folded thrust plane, along which the Georgian rocks have everywhere been overthrust over the Ordovician rocks. This condition is, in our opinion, a structural feature of the first magnitude of the entire plateau. Likewise the underlying Ordovician is not only compressed into small folds from the east, but also more or less bodily overthrust over the series of rocks of the Western basin. The same intense pressure which only a few miles farther east caused the regional metamorphism of all these shales, has to be considered as competent to produce the folding and the extensive overthrust faulting.

The facts which induce us to consider the entire western part of the Cambrian area at least as overthrust on the Ordovician rocks, are of both structural and topographic nature. The strike of the Ordovician rocks in the Saratoga plain leads these rocks directly under the Cambrian rocks of the Greenwich plateau, as a glance on the Schuylerville map will show. While from the northeast corner to the foot of Louse hill the Snake Hill beds pass under the Georgian rocks, in the southeast corner of the quadrangle, north and east of Willard mountain, the Normanskill rocks disappear under the Georgian rocks. In several localities where rivers have breached the margin of the Cambrian Greenwich plateau, the Ordovician rocks can be traced upward along the river, forming reentrant angles in the outline of the Cambrian. Such a large reentrant or embayment is formed by Moses kill and another broader one by the Batten kill.

Very instructive are the cases of the Hoosic river and Deep kill. At Schaghticoke the Schaghticoke shale (of lowest Ordovician age) is exposed in the bottom of the river, while the hills to the north and south of the gorge, in the general strike direction of the rocks,

consist of Georgian rocks. Likewise at Grant hollow, where the writer found the Deep Kill graptolite fauna in the bottom of the gorge, the tops of the hills on both sides of the gorge are fossiliferous Georgian. The latter occurrence is of great interest because it connects the Ordovician shale belt, west of the overthrust line, with the large Mt Rafinesque-Rice Mountain "Outlier." If the Georgian rocks overlie the Beekmantown graptolite shale at Grant hollow, it can be inferred that this outlier is really a "Fenster," or a portion of the Ordovician rocks underlying here the Georgian mass, but exposed by erosion.

There is considerable and quite conclusive evidence that the thrust plane is irregular in its hade, through folding; for while the thrust plane is very slightly inclined at Bald mountain and the Moses kill, it is steep east of Willard mountain, and in the neighborhood of Troy. That these differences are due to folding of a character transversal to the general northeast strike of the beds is indicated by the fact that where the hade is steep, the Georgian rocks descend deeper than where it is flat, as in the valley of the Batten kill, these regions corresponding to depressions or synclines.

There is considerable evidence extant of folding of the entire region long after the Green Mountain revolution, marking the Ordovician-Silurian boundary, and which is considered responsible for the principal folding and overthrusting of this region. Such later folding is shown by the folded condition of the Rensselaer grit, that is probably of Upper Devonian age, and the remnants of the folded and overthrust Devonian limestones still found along the Hudson river. We have here especially in mind the Kingston region, the folded and overthrust structure of which has been so well worked out by Van Ingen and Clark.¹ These authors have shown there the presence of a practically horizontal overthrust plane, the thrust of which comes from the east and which is possibly a manifestation of the same force that pushed the Georgian rocks over the Ordovician rocks on the other side of the Hudson.

The question whether the overthrust at the western edge of the Cambrian area recognized by both Doctor Dale and the writer, reaches so far back east that the large Georgian area is all over-

¹ Gilbert van Ingen and P. Edwin Clark. *Disturbed Fossiliferous Rocks in the Vicinity of Rondout, N. Y.* N. Y. State Mus. Bul. 69, p. 1176. 1903.

thrust upon Ordovician rocks as an extensive "carriage," is one that is exceedingly difficult of solution on account of the intensely folded condition of all the rocks involved and this condition is the cause of differences of opinion. We differ from Dale in the eastward extension which in our view this overthrust faulting has attained. We have already above presented evidence that some of the "outliers" of Ordovician rocks on the Cambrian plateau are not such simple outliers, as claimed by Dale, but "Fenster" (windows), that is, portions of the underlying but younger Ordovician rocks exposed by erosion, and the very small outlier of Ordovician at Sudbury, under which Dale¹ found Georgian rocks can not be considered as vitiating the other evidence on account of its small size (but 50 square meters) and nearness to a larger Ordovician body, which suggests that it may be but the remnant of a small infolded mass, such as are apt to occur near the Georgian-Ordovician boundary on account of the contorted condition of the rocks. Those "Fenster," which we have in view, as especially that connected with the Ordovician shale belt of the Hudson River plain by the Deep kill gorge (see page 112) lie close to the western edge of the Georgian area, and indicate an overthrust plane as far east as they extend. We see strong evidence for the far eastward extension of the overthrust in the appearance along the western edge of the Georgian area of such rocks as the Bald Mountain limestone, which are totally different from the rocks of the northern trough, and also lacking in the broad belts of shales of the Western trough to the north and south, and which therefore must have been brought a considerable distance from the east, if we will not assume that the limestone was again eroded over most of the area before or during the deposition of the Normanskill shale, an assumption that seems supported by the Rysedorph Hill conglomerate.

The evidence which has been gathered by us in this relatively small area, regarding the overthrust condition of the rocks, is in full accord, as far as it goes, with the views expressed by Ulrich in the Revision of the Paleozoic System, page 442, on the overthrust troughs in eastern New York and western New England.

¹ T. Nelson Dale. The Ordovician Outlier at Hyde Manor in Sudbury, Vt. *Am. Jour. Sci.*, 33:97. 1912.

Doctor Ulrich distinguishes five different Eopaleozoic troughs, going east from the Adirondacks, first, the Chazy basin, then the Levis channel, a third trough which contains the marble formation in western Vermont and succeeding limestone and shale formations, and possibly the Lower Cambic (Georgian) deposits. The fourth trough is supposed to have contained the Lower Cambic deposits, and a fifth trough, or rather set of troughs, is thought to be indicated by the highly metamorphosed Paleozoics found to the east of the Lower Cambic outcrops. The evidence on which Ulrich bases his belief in the existence of these troughs is threefold: (1) the differences in fossil contents of the sets of beds; (2) the peculiarities in the succession of the various general types of sediments; and (3) the physical proof of excessive folding and overthrusting.

We have in the two sheets here described undisputable evidence of at least two parallel troughs in the two entirely different sets of formations described above. These are the lower Mohawk trough in the west and the Levis trough in the east. If the Georgian and Bald mountain rocks belong to the third or fourth trough, this is also represented on the map. We have here considered them as underlying the rocks of the Levis trough, as they probably do, at St Albans and Georgia in Vermont (see Ulrich, *op. cit.*, page 493). It can not be doubted that the present position of the Georgian beds on the Schuylerville sheet above the graptolite beds of the Levis channel, and again the position of the latter above the beds of the Western basin require for the explanation of this complicated reversed position under the assumption that they represent but two troughs, a reversed anticlinorium with axial overthrust, as assumed by the writer in a former publication (Bulletin 42), or a complicated system of overthrusts and that the assumption of the original deposition of the Georgian beds in a third trough, which now has become pushed upon the second, will considerably simplify the history of diastrophic processes which have led to the present structure of the region.

The cause of these far-reaching overthrust phenomena which are observed in the whole Appalachian system is the pressure attributed to deep-seated "suboceanic spread" which results from the greater density of the terrestrial crust under the oceanic basins,

and which is the cause of the Appalachian and Green Mountain-Taconic fold systems but which also, as Ulrich lucidly shows, causes contraction of these tracts of the eastern continental coast by overthrusting, where deep-seated buttresses, as the Adirondacks are opposed to the folds.

One of the overthrust planes which have been observed on the Schuylerville sheet, namely, that separating the Georgian rocks from the underlying Ordovician beds, can be traced southward along the western edge of the Georgian to a locality near Schodack Landing, about 15 miles south of Albany, where the Georgian belt terminates near the Hudson. It is now an interesting fact that in the direct southwestward continuation of the overthrust plane similar overthrusts can be observed along which the Silurian and Devonian rocks have been moved westward. Chadwick has described such a fault from Saugerties,¹ about 30 miles southwest from Schodack Landing and between the latter place and the large overthrusts at Rondout, described by van Ingen and Clark. If these overthrusts all belong to the same orogenic movement, the latter is at least of post-Devonian age and probably dates, like all the typical Appalachian orogenic movements, from the close of the Paleozoic era, or is still younger.

THE NORTHUMBERLAND VOLCANIC PLUG

BY H. P. CUSHING

One mile north of the village of Schuylerville, near the Hudson river, is a knob of volcanic or effusive rock of quite exceptional occurrence. Woodworth was the first geologist to recognize its true nature and to describe it.² Since 1901, when his study was made, a considerable part of the knob has been quarried away for road metal and other purposes, exposing many features of the occurrence which were not originally visible, and also furnishing comparatively fresh rock for chemical study. The reader can obtain some conception of the differences between the knob as seen in 1901 and as it was ten years later by comparing plates 17 and 18.

Woodworth proposed the name of Stark's knob for this hill. The name is a convenient one, and will be here used in referring to it. Since the appearance of his report, Schuylerville people speak of it as "The volcano."

¹ G. H. Chadwick. Downward Overthrust Fault at Saugerties, N. Y. N. Y. State Mus. Bul. 140, p. 157.

² N. Y. State Geol. 21st Rept, 1901, p. 117-24.

This occurrence of volcanic rock merits detailed description, both because it is unique and because it is puzzling. It is unlike any other known occurrence of igneous rock in the State or in the neighboring states.

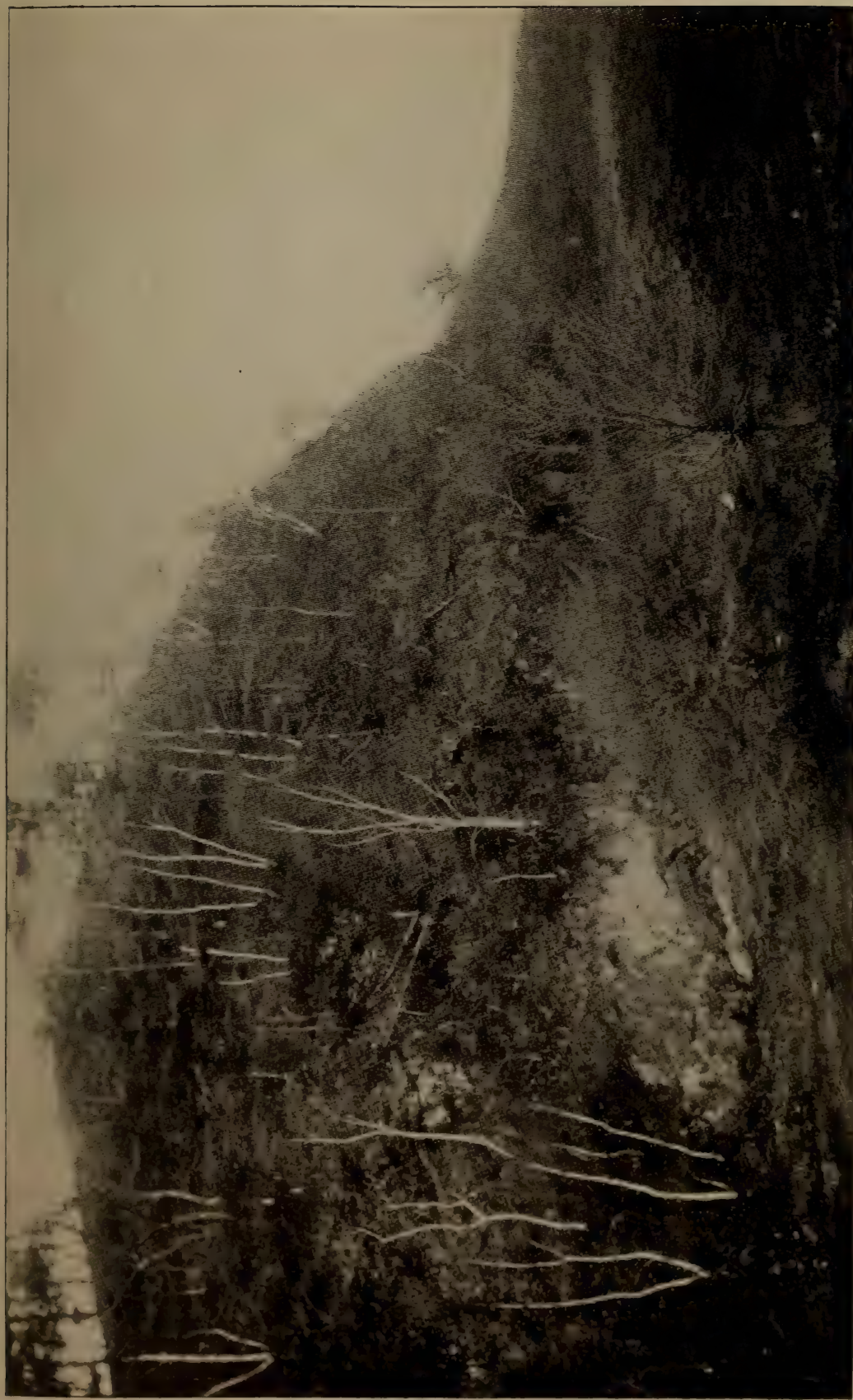
Woodworth's original description of the knob is so excellent that we can not do better than to quote freely from it:

The right bank of the Hudson river here consists of the usual bluff of Hudson River slates partly masked by Pleistocene clays. The igneous rock, being more resistant to erosion than the fragile slates, has withstood better the glacial erosion to which the region has been subjected and therefore stands out as a sort of buttress from the main wall of the inner Hudson valley or gorge. Much like the volcanic necks and plugs about Edinburgh in Scotland, this hard mass has been deeply scoured at base on the ice-struck side. In fact, all of the present relief of this plug and the adjacent river valley is due to the action of the river combined with that of the ice sheet of the glacial period.

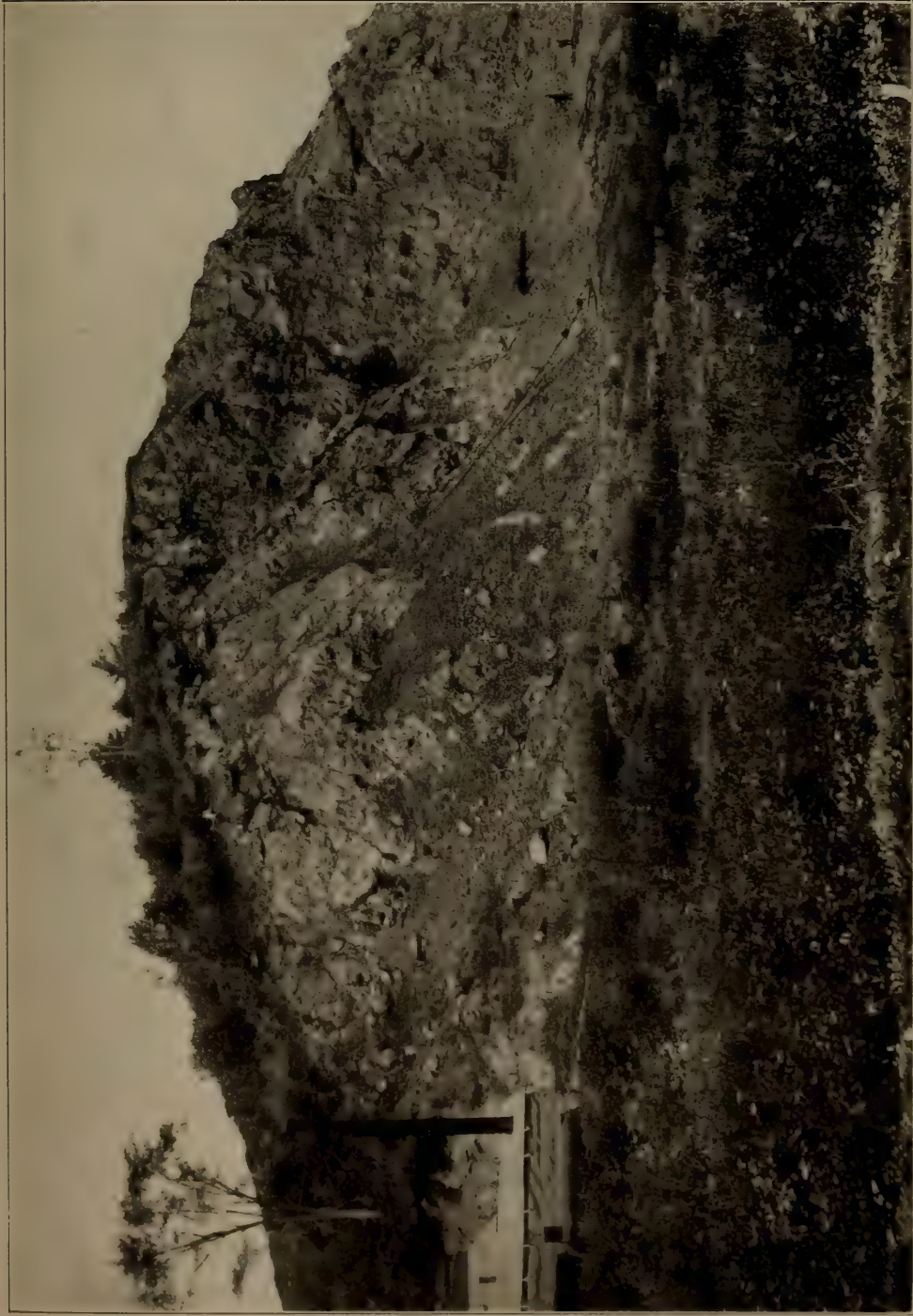
The summit of the knob scarcely attains the level of the upland which lies west of the river. A slight depression west of the plug serves to give it the appearance of a low knob when viewed from the upland, but at a distance it is relatively inconspicuous. This fact, taken in connection with the dark color of the rock in which respect it closely resembles the adjacent Hudson series, perhaps accounts for its going so long unnoticed or at least undescribed by the geologists who have passed through the upper Hudson valley. There is no mention of the knob by Peter Kalm or later observers; yet it appears from Brandon's historical map of Old Saratoga that General Stark of the American army occupied the eastern base of this knob during the Battle of Saratoga.

Stark's knob igneous mass lies surrounded on the ground by the Hudson River (Normanskill) slates. These are highly inclined, cleaved, and much broken rocks with a general northeast strike. So far as my own observations go, there are no small dikes radiating from the main igneous mass into the adjacent cleaved sedimentary rocks, nor are there any noticeable signs of metamorphism in these rocks attributable to the heating action of the lavas in the plug. The Hudson river group throughout this region is somewhat altered, but not more so at Stark's knob than remote from it. . . . This lack of contact metamorphism, unless such alteration be limited to baking, which was not observed in the accessible portion of the contact, and the failure of apophyses or branching dikes, are points of little value in determining the origin of the igneous rock in the knob. It remains to determine by other evidences whether the rock is intrusive or extrusive.

On the southeast side of the igneous mass and dissecting its border are two faults; that on the eastern side strikes n. 9° e., that on the southeast, n. 54° e. The southeastern fault is downthrown on the northwest, as on this side there is to be seen the slate underlying a mass of trap on the southeast of the fault. The complete relations of the igneous to the sedimentary rocks on this side are not shown. Figure 9, which is a diagrammatic representation of the cross section of the knob and its peculiar internal structure, shows



Volcanic plug, Schuylerville, Saratoga county. View from the east showing relief of the knob and accessibility of the rock for road metal. H. C. Magnus, photo 1961



Stark's knob in 1910 from the southeast. Removal of rock has chiefly been from the south end; on the north it has been stripped though but little has been removed. The arrow points toward the slickensided surfaces and shows the position of the camera for plate 19.

H. P. Cushing, photo



this fault, but the figure is purposely drawn with some vagueness on the extreme left of the igneous rock.

To sum up the geologic relations of the Stark's knob igneous mass, it is surrounded on all sides by the Hudson river slates. The principal mass is relatively faulted down into these sedimentary rocks on the south and east. To the eye there appears no distinct evidence of contact metamorphism; yet the mass appears to be the superficial portion of a body which extends downward into the slates and, from its general form and surroundings, strongly suggests a neck or plug rising up through the Hudson river group at this point. The manner in which the slate body dips beneath the igneous mass on the northeast, expressed in figure 9, appears to indicate that the neck or plug does not extend vertically downward through the slates but follows guiding planes of structure. It is conceivable that the igneous rock once overlay the surface of the slates, has been tilted with them in one of the orogenic movements of the region, and has subsequently been faulted

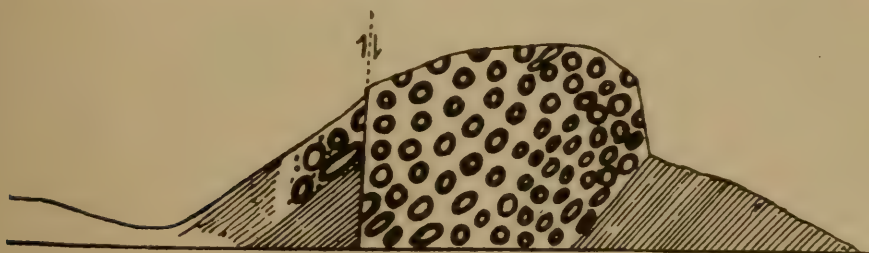


Fig. 9 Cross section of Stark's knob, showing general relation to the slates, and the gross ball structure of the mass

and thus separated from other masses of igneous rock which are now removed by erosion; but this view is not borne out by the observed geologic relations as now exposed.

Structure of the Stark's knob rock. The rock of which Stark's knob is composed is complex in structure. The exposed faces exhibit cross sections of ball and pear-shaped masses embedded in a base having a shaly structure. The crust of these balls consists of a layer of a dense, dark colored basic rock of the diabase type, surrounding a variable nucleus of ashy, rather porous, pumiceous-looking lava in most cases, and more rarely an included marginally absorbed fragment of white, semicrystalline limestone.

The line of demarcation between these three elements in the rock structure is usually very sharp and, where the shaly, fine grained base has peeled away from the surface of the lava balls, the surface of the latter resembles the coarse, bulging flowage surface of basalt streams, such as are seen in Hawaii. The whole has the appearance of a mass of bombs or lava balls inclosing scoriaceous lava, or foreign inclusions embedded in a basaltic glass which has devitrified and is scaling to pieces along lines of flowage. A more probable explanation of the structure is that this mass represents a volcanic throat or plug at some depth below the actual vent or crater but not below the point to which explosive products may have fallen back in the volcano there to become embedded in still hot lava. Certainly the gross structure of the rock recalls many lava sheets with locally formed explosive products, and the same structure is to be observed in the lava flows of the Newark formation

of Triassic age in the Connecticut valley¹ (figure 10). The accompanying photograph, plate 17 of the walls of Stark's knob shows the general structure.

The fragment shown in figure 9, lying south of the fault, is more massive than the main stock, and the ground mass approaches more nearly the dense, dark basalt, but here are also developed amygdules.

A hand specimen obtained here displayed fairly coarse crystals of plagioclase, indicative of an intratelluric origin, such as are common in the diabase of many dikes. This combination of the characteristics of dike rocks and of effusive explosive products makes Stark's knob one of the most interesting igneous occurrences, small as it is, within the limits of the State.

Jointing of the lava crusts. The surfaces of the lava balls are beset with a network of cracks perpendicular to the surface. On exposed walls the lava crusts frequently fall to pieces in short, polygonal joint columns similar to basaltic columns.

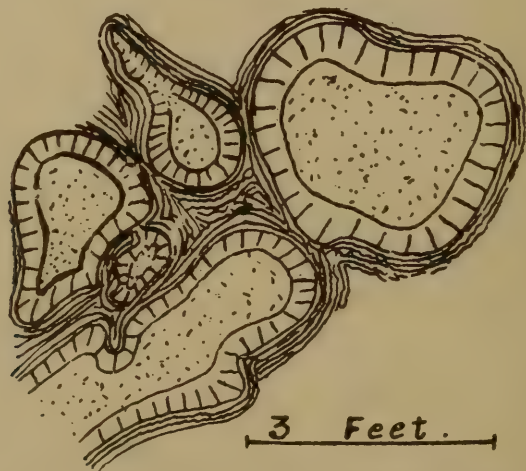


Fig. 10. Sketch of a portion of the western wall of Stark's Knob, showing the gray, scoriaceous interior of the lava balls, the basaltic, jointed crust, and the fissile, devitrified, volcanic glass surrounding the lava balls

The inclusions of limestone point to an irruption through the lower Paleozoic limestones which must occur in this field beneath the Hudson terrane. The inclusions may be appealed to as evidence that the trap came up through the Silurian and subjacent terrane, as held in this paper, and that the rock is not to be regarded as an in-faulted remnant of a lava flow once covering the Hudson terrane in this vicinity.

Since Woodworth's study of the knob, the rock has been utilized for various purposes and largely quarried away. We visited it in 1910, in 1911 and in 1912. In 1910 active quarrying was in progress; in 1911 this was not the case but much material had

¹Emerson, B. K. Diabase Pitchstone and Mud Enclosures of the Triassic Trap of New England. *Geol. Soc. Am. Bul.* 1897. 8:59-96. For an illustration of the ball structure at Meriden, Conn., see Davis, W. M., *The Lost Volcanoes of Connecticut*. *Pop. Sci. Mo.* 1891, p. 221, fig. 1; *U. S. Geol. Sur.* 18th Rep't. 1898. pt 2, p. 65.

been removed since our previous visit; between this and 1912 yet more was removed, until now comparatively little of the volcanic rock remains above ground. In addition to our own study of the occurrence we have had the advantage of visiting it with other geologists, with Van Ingen and with Smyth in 1910, with Kemp in 1911 and with Woodworth in 1912.

The result of opening up the knob has been to bring to light certain structural features that Woodworth could not possibly have observed in 1901, and to furnish fresher material for microscopic and chemical study than was available to him. Other features showed better on the old, weathered surface of the rock than in the fresher interior.

Constitution of the knob. The knob consists of lava balls, large and small, with intervening material. The balls range up to 2 feet in diameter. At the time of our first visit many of them lay about, being broken up by the quarrymen. In these we were unable to verify Woodworth's observation that they consisted of a dense exterior and more porous nucleus, though these two layers appeared plainly on the weathered surfaces which he saw. A probable reason for this may be that in quarrying, this exterior crust comes away with the intervening matter, leaving the balls free from it. The deforming agencies which have acted upon the knob may well have had this result. The balls, as we saw them, always had slickensided exteriors, and consisted throughout of similar material. Judging from all the data, it seems probable to us that the balls had originally a glassy crust and finely crystalline interior, and that shearing has separated the crust and nucleus so that they do not come away together in quarrying. For the most part the balls consist of dense, black rock, so finely crystalline that crystals are neither visible to the eye nor to the lens. Exteriorly the balls are occasionally amygdaloidal, but there is no great quantity having such texture.

The intervening material has been badly sheared and crushed, so that much of it has the appearance of slickensided, shaly matter. But some of it is less damaged, especially in the vicinity of limestone inclusions, which seem to have acted to prevent crushing; and here the rock is always of glassy texture, a black pitchstone. This is also sometimes amygdaloidal; and this amygdaloidal glass differs so greatly in appearance from the other amygdaloid, that we took it in the field for variolite. This, however, it does not seem to be.

The cracks which ramify everywhere through the lava are, for the most part, solidly filled with secondary calcite. The amygdules are chiefly of this mineral also.

Woodworth described coarser grained rock, containing feldspar crystals visible to the eye, from the south end of the knob, and the correctness of the description was verified by Cushing's study of the thin section. But we have been unable to find any rock of this type in our later work. Some rock has been removed from the south end though the original thickness was but slight. None of this coarser material remains and we are left in entire uncertainty as to its original amount.



Fig. 11 Natural size drawing of a hand specimen of corroded limestone in pitchstone

The inclusions. Inclusions abound throughout the plug, both in the lava balls and in the intervening material. They are *all* of limestone, and limestone of but a single type. Though the knob stands surrounded by black shales, there are no shale inclusions in it. It is possible that there may be inclusions of earlier trap, and the coarser grained rock just mentioned may be an inclusion. But on this point we have no certain evidence.

The inclusions are of pure limestone, effervescing briskly and immediately with acid. They range in size up to masses a foot

or more in diameter. In the balls they show but little sign of corrosive action, but in the glassy, intervening matter they are often considerably corroded by the igneous rock, resulting in the production of most curious shapes (figure 11).

In the specimen figured, the lava attack was probably from the front instead of from the right hand, thus lessening the amount of apparent corrosion, though a large margin remains. These corroded inclusions are in the pitchstone, while those in the balls show but little corrosion and but a trifling selvage of surrounding glass.

The two matters of chief interest concerning the inclusions are, the source of the limestone and the reason for the absence of other inclusions, especially those of shale.

The limestone of these inclusions is slightly reddened, presumably a result of heat from the lava, and is finely crystalline in texture, likely due to recrystallization on heating, though this is not certain. The inclusions are all of the one type of limestone. They must have been brought up from below ground by the rising lava, which must have passed through such a limestone formation during its ascent.

The only rock formation of the region which could have furnished such material is the Bald Mountain limestone of the eastern basin. In the western basin deposits we have the Hoyt and Amsterdam limestones, but they are separated by the great thickness of the Little Falls dolomite. Had the inclusions come from this series there would unquestionably have been an abundance of dolomite fragments in the lava, while actually there are none. But the Bald Mountain limestone has shales above and below. It also has many dolomite beds in its lower portion, so that it is surprising that there are none in the lava, if the inclusions really came from this formation. The question of the source of the inclusions becomes of much importance in the discussion of another problem, and we must later return to it.

The knob is surrounded by black shales, chiefly Normanskill, and it would seem that the lava must have risen through a large thickness of such shale. There are also frequent beds of hard, sandy grit in the shale. Under the circumstances the utter lack of recognizable shale inclusions is most astonishing. There are some large masses of shale involved with the lava but it is questionable if they can be regarded as inclusions. There are a few grains of quartz observable in the thin sections, and one patch

consisting of a dozen such grains. It is possible that these came from the grits. But if so, it is surprising that there are not larger fragments from the same source, since these grits are exceedingly tough and well-cemented rocks.

Structural features. The dissection of the knob by quarrying operations has brought to light some new structural features. Woodworth described two faults along the margin of the knob, and his section (figure 9) shows his conception of the relations of lava and shale. But quarrying brought to light other masses of shale, involved with lava, within the knob. We found evidence of severe compressive disturbance and dislocation all through the lava mass of the knob, suggesting a number of minor dislocations throughout the mass, instead of merely the two which

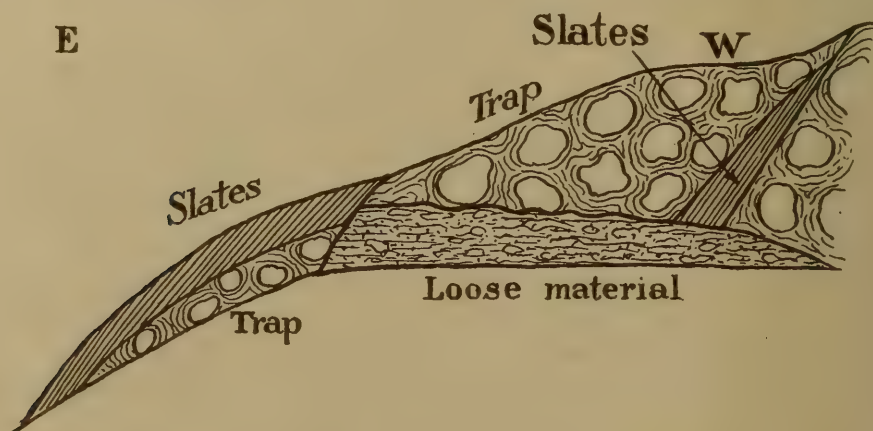


Fig. 12 Sketch of relations of shale and lava near the south end of the knob; shale overlying lava on the projecting point at the left, and a steep shale wedge in the lava midway

he saw, which were all that could have originally been recognized. A few sketches, and a comparison of them with our photograph of the knob (plate 18), will aid in the presentation of the details.

Figure 12 is a diagram of the south end of the quarried face of the knob, with a projecting point on the left which remains unquarried. On that point, slate overlies trap. Woodworth's section, in which trap overlays shale, was made a little farther south, and the remnants may be seen just over the roof of the engine house in plate 18. To the north of the point, shown in the sketch, trap makes the full height of the face and the shale has pinched out, but up this face runs another very steeply inclined, shale wedge, which runs nearly to the top before pinching out. Because of the section which Woodworth saw and figured, he judged a

fault must lie between it and the main mass of the knob. But these other shale wedges within the trap mass suggest the query whether the shale in Woodworth's section may not also be a wedge with trap beneath.

At the extreme north edge of the knob is another projecting point, remaining unquarried. A portion of this point is shown at the extreme right in plate 18, though most of it did not get into the view. Figure 13 is a sketch of the relation here.

It is not certain whether the shale here was originally a wedge within the trap, or whether it formed the lower part of the shale cover of the trap on this side, into which a thin sheet of the lava was extruded, or whether it is due simply to dislocation.

The shear zones. In the nearly vertical shale wedge shown at the right in figure 12, the shaly material is greatly sheared and

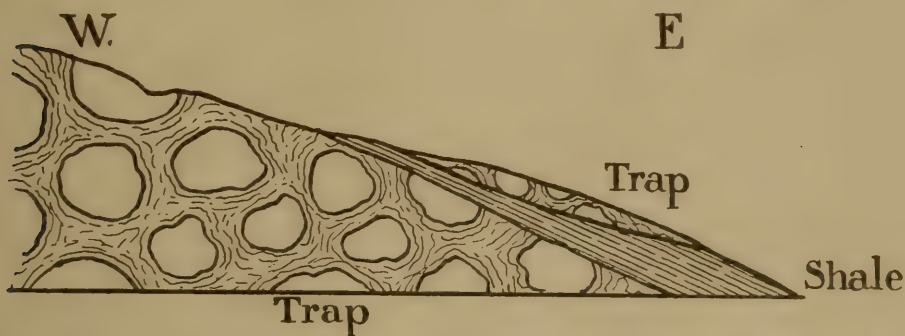


Fig. 13 Sketch of relations of shale and lava on point at the north end of the plug, showing a shale wedge with lava above and below

slickensided, as are also the trap surfaces adjoining the shale. The grooves and scratches on the slickensided surfaces are nearly horizontal in attitude, showing that these two parts of the knob have undergone lateral dislocation along a northwest-southeast line.

Within the northern half of the knob excavation has brought to light another great shear zone, nearly vertical and bearing north-south. There is no shale wedge here along which displacement has taken place, but merely a shearing past each other of the two adjacent parts of the knob, with production of a highly polished and striated contact surface. As in the previous instance, the striae are nearly horizontal, in no observed instance departing more than 20° from it. Here again there has been lateral displacement under conditions of load; in other words, it is inconceivable that these surfaces of hard trap rock could have been so thoroughly smoothed and polished when undergoing lateral slip

past one another except under the weight of a considerable thickness of overlying rock.

In addition to these two great zones there are a host of minor shearing planes all through the knob, all showing slickensides on their faces, with usually horizontal striae. The lava balls always show exterior slickensides, and the intervening matter is everywhere greatly sheared.

During 1910 great sheared surfaces became exposed at the base of the excavations in the central part of the knob. The sheared material had considerable thickness and consisted of a mass of shaly, thin plates, with beautifully polished slickensides on all surfaces. The sheared zone had an easterly dip of about 40° and seemed to pass with that inclination entirely through the knob, from bottom to top. It was actually disclosed only for about one-third of the whole height. Plate 19 is a photograph of a portion of this sheared mass, showing the shaly material in considerable thickness. At the time it did not occur to us that this was the actual base of the trap, and we interpreted it as a shear zone within the mass. At subsequent visits it was found covered largely by quarry debris, so that it showed but poorly. We learned, however, that the material had been drilled into for a depth of 12 feet, in search for additional trap underneath, but that none had been found within that distance. This suggests that we have here the actual base of the lava. The material does not exactly resemble the ordinary shale, however, and there is some reason for the belief that it represents a sheared mixture of shale and lava. Here again the striae on the slickensides approach the horizontal.

There is one more indication of dislocation in the knob; its back seems to be broken. This becomes quite evident to the observer on the summit of the knob, looking down into the excavation. The main shear zone in the northern half of the knob trends N. 10° E., which is also the trend of the lava mass there. The southern half, however, trends N. 45° W. and its main shear zone does likewise. The knob appears as if it had been cracked in two midway by a vertical rent, and the two halves twisted out of alignment through an angle of 55° .

All the evidence indicates that the lava of the knob has experienced compressive dislocation of the same type as have the overthrust shales in whose midst it lies; of the same type and quite comparable in amount.

Plate 19



H. P. Cushing, photo, 1910

Slickensided shaly material on Stark's knob, as it appeared September 1, 1910. The position of the exposure is shown by the arrow in the previous plate.

If the great diagonal shear zone just described lies at the actual base of the lava, as we suspect, then the lava forms a short, sheet-like mass inclosed in the shales and dipping in conformity with them, as shown in figure 14.

This corresponds with Woodworth's original conception as may be seen by reference to his figure (figure 9, page 117). The present relief of the knob is due to erosion, the trap being more resistant than the adjacent shales. The shale wedges in the lava may be due to lava tongues running out into the shales from the main mass, or they may be the result of dislocation. There is shearing and faulting in plenty to account for all the observed phenomena.

The lava then seems to lie within the shales after the manner of an intrusive sheet; yet it can not possibly be a sheet. In the first place it is altogether too short. At the north it ends very

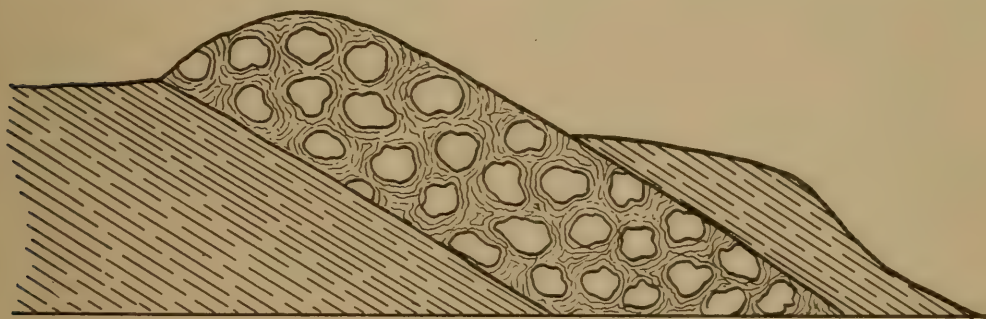


Fig. 14 Diagram of inferred relationship of lava and shales in Stark's knob

abruptly; a trench dug in the rock on the north slope of the knob is entirely in shale. At the south it becomes involved with shale wedges, and just south of the knob a poor exposure shows a thickness of about 1 foot of trap interbedded with the shales nevertheless here also the termination is fairly abrupt. The entire length along the strike from north to south is not over 200 yards. Moreover the nature of the lava itself, the ball structure and intervening glass, decisively negative any notion that we may be dealing with a sheet. The structure indicates surface lava, either a flow or a volcanic neck, a deposit in the throat of a volcano.

Microscopic characters of the lava. There are two chief varieties of the rock of the knob, the finely crystalline, dull, black rock of the balls, and the black glass of the intervening material. Both are locally amygdaloidal, but we saw no such material in place,

all coming from the dumps. The study of the exposures has led us to the belief that the balls may have had a glassy crust originally, and that this has been sheared free from them by subsequent movements. At present all glassy material is between the balls and most of it has been much crushed by shearing.

Thin sections from the rock of the balls show a network of minute feldspar laths set in what is certainly in some cases, and probably in all, a glass base. In the finer grained rock from the margins of the balls the laths have a prominent radial or spherulitic arrangement. The somewhat coarser rock from the centers has the same arrangement, but less prominently. The laths are minute and not greatly twinned. In the coarser varieties extinctions up to 20° are shown and the feldspar is probably andesine-labradorite.

In none of the slides is there any determinable pyroxene, nor anything which especially suggests altered pyroxene. In the finer grained rock it is quite certain that no pyroxene ever crystallized out; in the coarser rock some may perhaps have done so, as there are small scattered patches of calcite and possibly alteration products between the feldspars which may have resulted from pyroxene alteration. But we regard it as most probable that the stage of crystallization of pyroxene had not been reached in any of the rock at the time of solidification.

All the slides show occasional, sharply bounded areas which have the outlines of porphyritic crystals. A number of these seem quite certainly original olivines; the outer form and the angles are precisely those of that mineral. This has led to the belief that all are probably original crystals of olivine. They show three different types of alteration.

In type 1 the mineral is entirely gone to a fine, light greenish, feebly polarizing aggregate, which seems unquestionable chlorite. A few individuals show traces of a mesh structure which suggests serpentine, but this is by no means the rule. This is the more usual alteration.

In type 2 the original mineral is entirely replaced by calcite, fairly coarsely crystallized, or else by calcite and quartz. This is the same mineral combination found in the amygdules.

Type 3 is the least common and seems to be a further stage of the alteration shown in type 1. The material is either brown and wholly opaque, or else this with the addition of tiny, colorless patches which show faint double refraction.

All the slides contain crystals of black, opaque material. There are occasional small crystals of pyrite. There is much minute, dustlike material, especially in the glass, which may be magnetite, though it wholly lacks metallic luster, perhaps because of its minuteness. There is also much somewhat coarser material, of irregular outline which we should like to identify as graphite. The chemical analysis indicates a large content of carbon in some form, but in reflected light this material does not show a metallic luster such as graphite possesses, but takes on an even, whitish sheen which we are unable to compare with anything we have ever seen in thin section. It seems present in the slides in about the proper quantity to account for the carbon shown by the analysis and may be graphitoid, or some other carbonaceous residue, instead of graphite.

All the slides contain much calcite. It fills the amygdules, it occurs in irregular patches throughout the balls, and it solidly welds up the numerous cracks which run everywhere through the lava.

The calcite in the cracks gives clear evidence of the deformation to which the rock has been subjected since it solidified. It shows everywhere the close-set, multiple twinning, and the undulatory extinction produced by the deforming stresses.

At the borders of the limestone inclusions in the balls a slight chilling effect is manifest, and a narrow zone of glass containing much finely divided, black, opaque matter has developed. A slight amount of corrosion has also occurred, small fragments of the limestone appearing separated from the main mass and in all stages of solution in the lava, the resulting product being a clear, light green glass. Examples of partially corroded limestone surrounded by such glass are shown, together with others which suggest the utter disappearance of the limestone fragments, the glass indicating their original presence. The limestone has also been recrystallized by the action of the lava, the border of the inclusion being more coarsely crystalline than the interior.

The pitchstone which constitutes the intervening material is black, but becomes a clear, light green glass in thin section. It is perfectly clear and unaltered, a matter of some surprise when it is recalled how completely the olivines are altered. Except in the vicinity of limestone inclusions, it has been sheared and shows its condition of strain by being doubly refracting. It is locally

packed with tiny opaque inclusions, perhaps magnetite, shows an occasional pyrite crystal, and frequent irregularly bounded individuals of the material that we are assuming to be graphitic. At the contacts with limestone inclusions, clear evidence of limestone absorption is shown by the production of a zone of mingled material, calcite and glass, the relative proportions of which vary with distance from the contact. The glass is lighter in color and no longer clear glass, but full of very tiny crystals, often spherulitic, which are altogether too tiny for exact determination, but which appear to be feldspar. The addition of lime to the melt seems to have lowered the temperature of solidification sufficiently to permit at least the beginning of feldspar crystallization, while elsewhere the material solidified as glass. This intermediate zone is unquestionably one produced by direct solvent attack of the lava upon the limestone, and is thus corroborative of the evidence of this attack previously given.

The amygdules in the glass have the appearance of small, round, black bodies, when whole; when broken across, the interior filling is light colored but dull looking and not so white as in the case of the amygdules in the balls. The filling is the same in both cases, either wholly calcite, or else calcite with some quartz, both of fairly coarse grain.

Chemical composition. Since the rock from the centers of the large lava balls seemed in quite fresh and unaltered condition, except for the olivine, it was confidently expected that a chemical analysis would definitely show the composition of the lava, and would be attended by no especial difficulty. But analysis developed the presence of a considerable amount of carbon in the rock, rendering determination of ferrous iron very difficult, and showed also the presence of a large quantity of water. This also was difficult of exact determination. But Professor Morley has labored indefatigably at the problem. The ferrous iron was finally determined by bichromate titration. Professor Morley states that the results can not be vouched for to the single drop, as with permanganate, but that the uncertainty is not great; that he can not hope that the accuracy of the three determinations, Fe_2O_3 , FeO and $\text{H}_2\text{O}+$ is as great as that of the others but that he has every reason to believe in their reasonable accuracy. Our indebtedness to him for the painstaking labor and the eventual very satisfactory result is most emphatically expressed.

The water is no doubt present as a constituent of the glass. The interest attaching to the presence of carbon more than compensates for the slight uncertainty introduced into the analysis.

SiO ₂	47.55
Al ₂ O ₃	16.65
Fe ₂ O ₃	4.94
FeO	5.12
MgO	5.63
CaO	4.77
Na ₂ O	4.20
K ₂ O	2.52
H ₂ O+	5.57
H ₂ O—	0.24
TiO ₂	0.87
P ₂ O ₅	0.27
Cl	0.10
F	0.06
S	0.01
MnO	0.46
C	0.80
CaCO ₃	0.34
Total	100.10

Selected rock from the center of one of the large lava balls, as free as possible from calcite. E. W. Morley, analyst.

The calculated norm of the rock would be

Orthoclase	15.01	Olivine	12.64
Albite	33.01	Magnetite	7.19
Anorthite	18.90	Ilmenite	1.67
Nepheline	1.42	Apatite	0.67
Diopside	2.48		

Totalling 92.99 per cent; the residue consisting of water, carbon and calcium carbonate. The rock classifies in

Class 2, Dosalane	Rang 3, Andase
Order 5, Germanare	Subrang 4, Andose.

It is thus a member of a very large rock group, of diabasic or basaltic composition. It is quite near some of the Newark traps, that from Medford, Mass., analyzed by Merrill for example, though it is a more basic rock than the average Newark traps, which run from 52 to 53 per cent of silica.

The carbon¹ content was a wholly unexpected result. Gaseous compounds of carbon are emitted by most cooling lavas, but a considerable carbon content in the cold lava is most exceptional. Inquiry as to its source is naturally suggested.

The knob is surrounded by black shales, which at once suggest themselves as a possible source. There are no recognizable shale inclusions in the lava, but it might be possible that the explosive action of the eruption should have mingled a certain content of comminuted shale with it. The thin sections however give no suggestion of any such admixture, no shale particles being recognizable in them. And when it is recalled that, in such black shales, the entire content of carbonaceous matter does not usually exceed 5 per cent of the rock, it will be seen that the rock at the knob would of necessity contain from 15 to 20 per cent of shale, in order to give the carbon percentage shown on analysis, provided it came from this source. But neither the thin section, nor the chemical analysis give any suggestion of such an admixture.

A trifling amount of carbon may have been obtained from dissolved limestone, as this contains a small amount of organic matter; and the abundant opaque particles developed in the glass at the limestone contacts, definitely suggests something of the sort. But there is no evidence of a large amount of limestone corrosion, and the rock is low in lime, rather than high. It could not have obtained much carbon from this source.

There remain apparently two possible sources for the carbon. The heat of the intrusion may have liberated hydrocarbons from the shales below ground, which were then taken up by the lava, or the lava itself may have contained more carbon than usual originally, more than could be oxydized by the usual volcanic processes. Either process is unusual, but then the occurrence is itself unusual. Graphite does occur in igneous rocks, as for example in some of the Adirondack pegmatites. Its occurrence in meteorites is well

¹ Because of the interest attaching to the presence of carbon in an igneous rock, Dr H. S. Washington kindly volunteered to look over the thin sections, and to examine the insoluble black residues of the rock. In a letter received from him too late for incorporation in this report he states that the material is carbon, and is not graphite. He also makes the following suggestion to account for its presence, that it is not impossible that, under proper conditions of pressure and temperature, FeO will reduce Co^2 . He calls attention to the limestone inclusions as the source of the CO^2 , and notes that the carbon in the thin sections is in the glass, and not in the feldspars, hence associated with the iron-bearing portion of the rock.

known. It is quite possible therefore that it is here one of the primary minerals of the lava. But the comparatively large amount present, together with the rarity of its occurrence in igneous rocks, enforces caution in attributing such a source to it. In so far as possible derivation from the shale is concerned it must be stated that the associated shales in the vicinity of the knob show no indication of any loss of carbon due to action of the lava, or indeed of any change whatever, so that if we look to them as a source we must assume that the process only took place at greater depths. It would be a debatable question whether hydrocarbons, liberated from the shales by the heat of the intrusion, would migrate into the lava; whether they would not rather be driven away from it. Even if taken up why should they have been converted to graphite? All, or nearly all lavas contain carbon; but on cooling they give it off in combination with oxygen, or with hydrogen. Why an exception was made in this case we cannot say.

Is the lava in place? Stark's knob is a small mass of igneous rock inclosed in shales. The shales are greatly contorted and compressed everywhere, and the evidence, both structural and paleontologic, shows that they have been overthrust into the district from the east. The question naturally arises, May not the igneous rock have come into the region by overthrusting, along with the inclosing shales? We regret that we are unable definitely to answer this question. Were it true, certain of the structural features would receive a simple explanation. The shearing and dislocation of the rock would thus be accounted for, as well as its abrupt termination laterally, and the lack of dikes running out from it into the shales. We could understand the reason for the shale wedges inclosed in the lava. More latitude would be given in accounting for the inclusions, abundance of limestone of a single type and absence of all other rocks. The manner of occurrence in the shales, a short and comparatively thick mass of lava imprisoned in shales along their dip, would also not be so hard to understand. The shales are so cleaved that they usually come apart more readily on the cleavage planes than on the stratification. It is this character that makes it so difficult to collect fossils from them. It would seem that the explosive action of a volcanic vent breaking through them would have opened them vertically along the cleavage planes instead of following the incline of the dip.

If the lava solidified where it now rests, the only possible conception of the occurrence which at all fits the facts of the case is that it is a volcanic neck. But volcanic necks are usually nearly vertical, instead of quite inclined, as in this case; they usually cut across the bedding instead of following it; and they are usually filled with agglomerate, tuff or solid lava. We do not recall any account of a volcanic neck filled with material such as that at Stark's knob. The usual filling is generally much more distinctly fragmental in type and more diversified in character. On the other hand, we know of no reason why such material might not accumulate in a neck.

Many features of the rock of the knob recall very forcibly the characters of pillow lavas, characters produced (in many instances at least) in surface lavas when poured out so that they mingle with surface waters. Spheroidal masses of lava, production of glass, and explosive mixture with fragmental material from beneath, are the prominent characters of such lava flows. A great number of shrinkage cracks through the lava pillows is another feature possessed in common.

At Stark's knob there is no sign of the basal admixture with fragmental material, such as is found in many pillow lavas, unless indeed the shear zone material at the base may represent it, crushed beyond recognition, as an analysis perhaps suggests. Nor is the lava as highly altered as most pillow lavas are; yet this difference may be more apparent than real. Most such have been described from natural exposures, and exteriorly the rock at the knob was highly altered. The fresh material is due to quarrying and comes from many feet below the original surface.

Nor is the structure exactly comparable with that of pillow lavas, the chief difference being in the greater quantity of intervening material at the knob. We have seen that shearing has probably increased the apparent amount of this, the outer portions of the balls cracking and shearing away, especially where composed of glass. But when every allowance has been made for this it remains doubtful whether the balls were ever as closely packed and close fitting as in most pillow lavas.

In weighing the evidence for or against the lava being in place, with part of the evidence seeming to point one way and part the other, we must confess our inability to come to any definite conclusion in the matter. The overthrusting seems *a priori* so unlikely that our sympathies are entirely with the other view. But

we can not relieve ourselves of the suspicion that it may, after all, be an overthrust mass, a fragment of a surface flow which came up through and was poured out upon a surface of limestone, thus acquiring its inclusions, and later on thrust westward coming to rest with rocks with which it had originally little to do.

The inclusions. The difficulty of accounting for the limestone inclusions in the lava has already been mentioned. The inclusions are many, and all of one kind of rock, which seems perhaps referable to the Bald Mountain limestone, but certainly to no other of the rock formations of the region. The knob lies in the midst of overthrust shales. Just what their thickness is at the spot we have no means of knowing; but it is quite likely considerable, since they extend 5 miles farther west before thinning out to disappearance. In considering the manner of overthrusting in such weak shales it seems reasonable, if not obligatory, to suppose that the thrust was carried by some strong, competent stratum, on top of which the shales were carried westward. The Bald Mountain limestone is the first formation of the sort beneath the Normanskill shale, in the eastern basin section, and it is therefore not unreasonable to suppose that it is present underneath the shales at Stark's knob. If so it probably rests on the western basin rocks, most likely on Canajoharie shale. That the structure as a whole is not so simple as this, that the shales are jumbled indiscriminately together to a certain extent, is shown by the presence of Schaghticoke (*Dictyonema*) shale in the midst of the Normanskill near the knob. Were fossils more abundant, many such mixtures might be found. This suggests that a confused mixture of shales may have moved west even beyond the competent stratum which carried them, falling and being pushed in front of the main mass. The Bald Mountain limestone therefore may, or may not, be present below ground at the knob. If it is present it lies nearer the surface than any other limestone, with shales both above and below; and it is likely also to be in somewhat shattered condition, so that it would readily furnish inclusions to an igneous rock rising through it. The limestone inclusions can therefore be plausibly accounted for on the theory that the lava is in place. The lack of inclusions of shale is not thus explained; but the carbon content of the lava may have come from the shale, and its failure to furnish inclusions may be due to the physical nature of the rock.

So far as the inclusions are concerned, therefore, they do not aid in the decision as to whether the lava is in place or is not.

If the drill should show that the Bald Mountain limestone was absent below ground at the knob, a quite different face would be put upon the matter. But the drill has not been at work in the vicinity.

The age of the lava. Since the suggestion was made that the igneous rock of the knob might have some significance in connection with the theory of the juvenile origin of the Saratoga waters, the question of the geologic age of the rock becomes of more moment than would otherwise be the case. Unfortunately precise data are quite lacking.

When Woodworth and Cushing considered this matter, at the time of the original description of the knob, a Newark (Triassic) age was suggested by each of them, independently, as most probable. Then, as now, the only positive statement that could be made is that the igneous rock must be younger than the shales which surround it. Even this is not necessarily true, if it has been overthrust. The shales are of Ordovician age. There are known in New York three groups of igneous rocks which fulfil that age requirement, the dikes of the Champlain valley, the dikes of central New York, and the traps of the Newark series. The rock, in its characters, does not at all suggest the Champlain dikes; still less does it in any way resemble the peridotites of central New York; but it is quite similar to some phases of the Newark traps. Unless we referred it to the Newark we had no alternative but to regard it as representing igneous action of some other date, with no other known representatives in the State.

That still seems to us the most logical view to take in default of actual evidence to the contrary. The amount of deformation experienced by the knob seems a positive evidence of antiquity. The dislocations already described indicate deformation under load, under a considerable thickness of overlying rock which has since been eroded. The lava is of the effusive type, either a volcanic neck or a fragment of a lava flow. Since its formation it has been buried under other rock, deformed, and the overlying material removed by erosion. When or under what it was buried we have no means of knowing, since all trace of the material has since been removed; but if the lava is in place, continental deposits of Newark age seems the most likely supposition. It might have been later continental deposits. To be sure, the knob lies in a main valley of erosion surrounded by relatively weak rocks, so that conditions are favorable to rapid wear. But even making

every allowance for that it still seems to us that the very oldest Tertiary is the youngest age that can possibly be ascribed to the rock, all the conditions considered. Since igneous action of such age, or of any Tertiary age, is wholly unknown in the eastern United States, a reference to the Newark seems to us more reasonable. Yet we candidly admit the peculiarity of the rock and its isolated occurrence, and have no quarrel with anyone who is disposed to take a different view. There is one character of the lava which suggests recency, and that is the unaltered and undevitrified character of the glass.

To sum up, the only definite statement that can be made concerning the knob is that it consists of a small mass of lava of effusive type. If it is in place it seems surely a volcanic neck or throat; if not in place it may be a fragment of a surface flow, overthrust from some locality to the east. If in place it is younger than the date of the overthrusting; if not in place it is older. If not in place we have no idea whence it came, nor are any other fragments known. It has some features in common with certain Newark trap flows and is like some of them in composition, though the composition differs from that of the average Newark trap. Clear structural evidence of much shearing and faulting of the knob, of such type as to indicate deformation under load, leads to the conviction that the lava can not be an especially recent one.

HISTORICAL GEOLOGY

BY H. P. CUSHING AND R. RUEDEMANN

Precambric. Our direct knowledge of the events of Precambrian time in the region commences with the deposition of the Grenville series. These rocks are very widespread and very thick, with great amounts of shales and limestones and a lesser amount of sandstone. They must have been deposited on some floor of older rocks which has since been entirely destroyed by igneous action, or else yet remains to be discovered. Judging by their extent and thickness the series was probably deposited under marine conditions but, lacking fossils, there can be no certainty in the matter.

Following the deposit of the Grenville sediments the region was repeatedly invaded from beneath by great masses of igneous rock. The earliest and most widespread of these invasions was that of the Laurentian granite. Subsequently came invasions of anorthosite, syenite, granite and gabbro. These broke up the Grenville rocks into groups of fragments, apparently ate away and digested much

of the basal portion of the sediments and caused the complete disappearance of their old floor of deposit.

There followed a very long period of erosion of the region during which it was above sea level. A great thickness of rock was worn away from the surface, bringing to daylight the tops of the great igneous masses which originally solidified much below the surface. The final effect of the long erosion period was to have reduced the entire region to one of low altitude and small relief. Toward the close of this erosion period renewed igneous activity resulted in the formation of the trap dikes.

Paleozoic history. The Adirondack region then developed a tendency to dome upwards centrally and to sag at the margins. These sagging margins passed from time to time beneath sea level and received accumulations of deposit. In these troughs the early Paleozoic sediments of the region were laid down. Oscillations of level were of frequent occurrence, accompanied by warping of the region. Submergence in the different troughs alternated; it was the rare exception that all were depressed at the same time. In this report the deposits of the Champlain-Hudson trough (the so-called "Chazy basin") chiefly concern us.

To the eastward of the Chazy basin downwarping developed one or more other troughs, in which deposits quite different from those of the Chazy basin were laid down. Since their formation these rocks have been overthrust to the west upon the rocks of the Chazy basin, and directly adjoin them upon the east.

CAMBRIC HISTORY

Chazy basin deposits. Potsdam sandstone. The first Paleozoic deposit of the Adirondack margins was the Potsdam sandstone, an accumulation of coarse, quartzose sands and gravels. The accumulation began first on the northeast, in Clinton county, and extended itself progressively to the west and to the south. Only the upper portion of the formation is found in the Saratoga region.

This upper portion contains marine fossils and must have been laid down in shallow marine waters. But marine fossils are lacking in the lower half of the formation, in Clinton county, and many of its characters suggest that it was laid down above sea level instead of below it. They suggest also that the climate was arid. But whether marine or not, the accumulation began because the district sagged down. This sagging began at the north and slowly

extended southward up the Champlain trough, and westward up the St Lawrence trough.

The currents which transported these coarse sands and gravels must have been vigorous ones, suggesting rather strong relief of the land which lay to the south and west. All fine material was washed and blown to a distance.

The sands of the Potsdam are succeeded by the alternating sands and dolomites of the Theresa formation without any sign of a break between them. Erosion had lowered the bordering lands. Sand came down only intermittently and in less volume, and beds of dolomite began to be deposited. The sands steadily diminish in frequency and thickness, and thus the Theresa formation grades upward into the Little Falls dolomite. Both these formations are marine, but in both of them fossils are very rare, especially in the dolomite. The great reefs of *Cryptozoon*, which occur at many horizons, seem to indicate the likelihood of abundant life and to suggest that the scarcity of fossils is more likely due to unfavorable conditions for preservation than to their absence in the marine waters.

The Hoyt limestone is a local upper phase of the Theresa formation about Saratoga. It seems to represent a more offshore phase of the formation, and fossils are much more abundant than in the ordinary Theresa or the Little Falls dolomite. This may in part be due to the offshore character of the Hoyt, but it also suggests more favorable conditions of preservation.

These three formations are of extreme upper Cambrian age (Ulrich would class them as Ozarkian), and are the only Cambrian deposits that were laid down along the Champlain trough. Following their deposit mild uplift occurred and the troughs came above sea level, existed as land for a space, and were somewhat eroded. This erosion gently bevelled off the surface instead of deeply cutting into it, which suggests that the land was of low altitude.

ORDOVICIAN HISTORY

The uplift just mentioned forms for the geologist the dividing plane between the New York Cambrian formations and those classed as of Ordovician age. No one has any clear idea in regard to the length of elapsed time which this uplift represents. Eventually the troughs became again depressed and occupied by marine waters; and in these, on all four sides of the Adirondack region, the various

dolomite and limestone formations of the Beekmantown group were laid down. These are thickest and most complete in the Champlain trough which sagged more, and for a longer time, than the troughs on the other three sides of the Adirondacks. But the Beekmantown deposits of the Champlain trough do not occur in the Saratoga region, and hence do not especially concern us in this report. The Saratoga district is on the western margin of the trough, its axis lying to the eastward. The trough was submerged and emerged several times. The waters of some of the submergences overspread the Saratoga region, as in the case of the Little Falls submergence; but the others failed to reach the district. Apparently the Beekmantown waters fell just short of covering it. It is barely possible that the formation was thinly deposited and subsequently entirely worn away. Beekmantown rocks do not appear in the Saratoga section.

Emergence of all troughs followed the Beekmantown, the emergence being of unknown duration. Then the Champlain trough was depressed so that its northern portion passed below sea level and the marine limestones of the Chazy group were laid down. This depression seems not to have reached within 75 miles of the Saratoga region which remained persistently as an area of lowland throughout Beekmantown and Chazy time.

BLACK RIVER HISTORY

Apparently emergence of all troughs followed upon the Chazy depression. Because the immediate Saratoga region lacks deposits of Beekmantown and Chazy age, these episodes have been described as though each consisted of a single submergence and emergence. In reality minor oscillations of level took place within both groups. Depression of the troughs, in which the various formations of the Black River group were laid down, succeeded the Chazy emergence. In order of age the three chief formations of the Black River group are the Lowville, the Watertown, and the Amsterdam. Only the near shore edges of these formations are now exposed to view in New York. They are very patchy in distribution and were deposited along the oscillating margins of the troughs, now above sea level, now below. The thicker deposits of the central portions of the troughs are not shown in surface exposures today, but lie farther away from the Adirondacks, buried under a cover of later rocks.

The Amsterdam is the only Black River formation deposited over the Saratoga region. The margins of the Lowville and Watertown troughs did not quite reach the district, and the Amsterdam rests on the Little Falls dolomite. It is the oldest Ordovician formation of the quadrangle. Between the deposition of the two the region stood as a land area on the margin of the Champlain trough. The small amount of erosion of the Little Falls surface during this long interval is indicative of low altitude of the land.

The pure limestone of the Amsterdam denotes also low altitude of the neighboring land. The abundance of marine fossils shows plentiful life in the waters.

Uplift followed Amsterdam deposition, the Saratoga region passing slightly above sea level.

Succeeding this uplift came the Trenton submergence. At first, beds of limestone and of blackish shale alternated with one another; but the limestone soon ceased and the great thickness of the Canajoharie shale of lower Trenton age slowly accumulated in the subsiding trough. The fossils are chiefly graptolites; open sea forms swept into the trough by marine currents which ran through it. Conditions were not favorable for an abundant and diversified marine fauna.

During this same time Trenton limestones were being deposited on the west side of the Adirondacks, in clearer seas which swarmed with marine organisms. Conditions on the two sides of the region were thus sharply contrasted.

In middle Trenton time the deeper Canajoharie sea which extended from the Mohawk valley northward through the Chazy-Saratoga basin into Canada and southward through the Hudson river region and as far south as the southern Appalachians, was probably drained for a brief period in this region, but soon again the shallow sea of the Schenectady period extended through the trough northward to an unknown extent, but undoubtedly across the Saratoga and Schuylerville quadrangles. The bottom of this trough kept sinking gradually, so that upward of 2000 feet of shallow water deposits could be accumulated in it in Schoharie and Schenectady counties.

In the following Utica period this region was probably again emerged, for no Utica deposits have as yet been recognized in the lower Mohawk and Hudson valleys, the so-called Utica beds of these regions all being now known to be of Canajoharie age. It

is, however, also possible that a thin edge of the Utica formation reached here around the southern Adirondacks, but was again eroded before the Indian Ladder sea crept over this region from the south. This latter formation consists, at the Indian Ladder, mainly of soft shales with some sandstone and calcareous bands, and seems to have been deposited in a slightly deeper sea than the Schenectady beds.

As we have seen before, there are exposed in the shale belt rocks of two entirely different sets of formations which represent sedi-

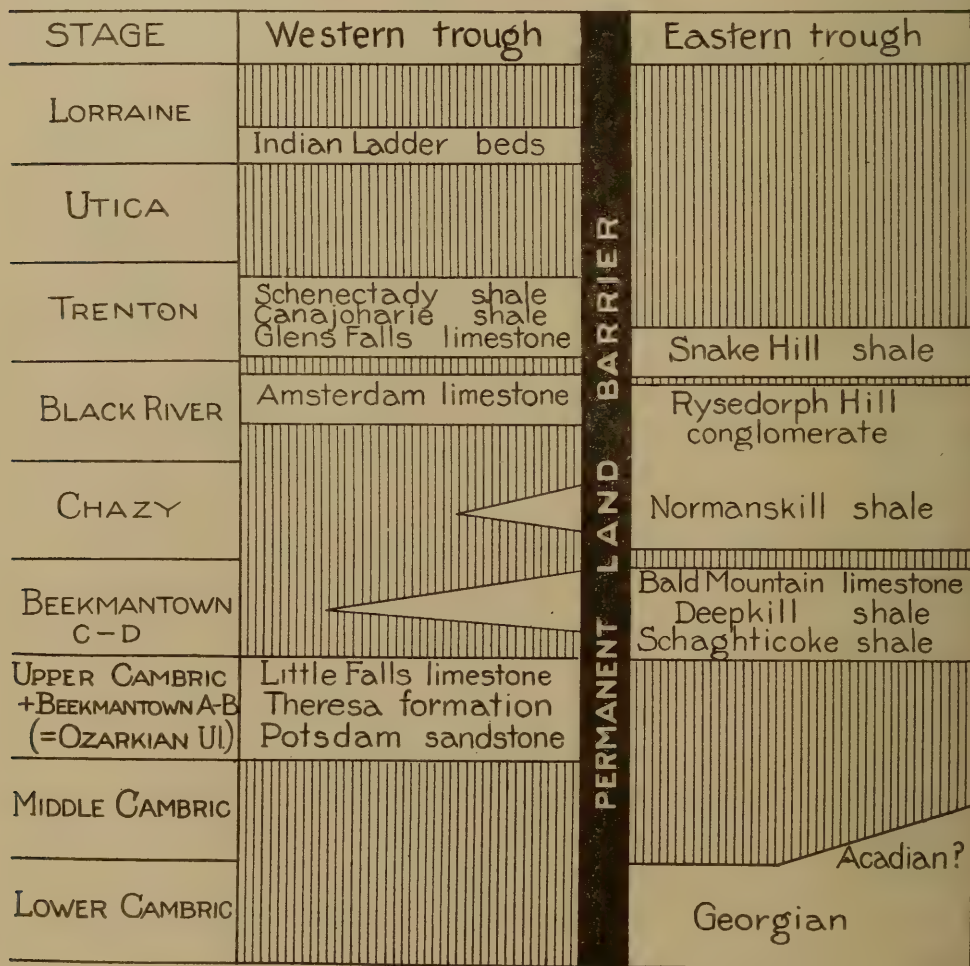


Fig. 15 Diagram of time relations of formations of the eastern and western troughs on the Saratoga-Schuylerville quadrangles. Shaded intervals indicate probable emergences

ments deposited in two different troughs, the western or lower Mohawk trough and the eastern or Levis trough; and if the Georgian beds represent a third trough (see above, page 114), even sediments of three basins.

We have represented in figure 15 the events going on in the two troughs, as far as the Saratoga and Schuylerville quadrangles are concerned, during Cambrian and Ordovician time, where the shaded periods represent emergences and the unshaded the submergences. It is seen at once that frequent oscillations took place in both basins and that the invasions of the sea and withdrawals did not take place simultaneously in both basins, but at very different times and apparently independently of each other. It appears, however, that there is recognizable a certain approximate alternation of the invasions of the sea in the two basins, indicating an east-west shifting of the seas in the troughs, such as has been observed in more complete development by Ulrich (1911, page 543) in the Ordovician seas of the Appalachian valley troughs in east Tennessee. Moreover, the invasions came partly from the northeast or Atlantic basin and partly from the Gulf and Pacific basins.

The Lower and Middle Cambrian time finds the western trough entirely drained of the sea, while at the same time a great mass of sediments was deposited to the east, the Georgian in the Levis trough, and the Acadian in still more easterly troughs, and possibly also to a limited extent in the Levis trough. This invasion came from the north.

In the Upper Cambrian the scene of submergence shifted entirely into the neighboring westerly trough, where invasions first from the north and then from the southwest brought the Potsdam sandstone, the Hoyt limestone and Little Falls dolomite, while the eastern trough or Levis basin was at the same time raised above sea level.

During Beekmantown and Chazy time that part of the western trough now exposed was apparently drained in the area of the two quadrangles here described, the rocks of the two formations being absent between the Little Falls dolomite and the Amsterdam limestone. They are, however, present but a short distance north in the Ticonderoga-Crown Point region, and the sea in both the Beekmantown and Chazy times, nearly reached the quadrangles in this basin from the north, or it actually reached there in the more eastern, deeper parts of the trough which are now buried under the overthrust shales of the eastern trough. The sea did reach into this latitude and beyond, coming from the north, in the Levis trough, where the Schaghticoke and Deep Kill graptolite shales and possibly also the Bald Mountain limestone

of upper Beekmantown age were deposited in Beekmantown time; and after a brief emergence, the Normanskill shale of Chazy age, which in its turn was followed after another short emergence by the sea depositing the Upper Normanskill shale with the Rysedorph Hill conglomerate and the Snake Hill shale. It appears that this whole group of Ordovician seas of the Levis trough invaded from the north. The north connection is shown by the faunas and areal distribution of the Schaghticoke, Deep Kill and Normanskill shales, by the Atlantic faunas of the Rysedorph Hill conglomerate, and it is suggested by the fauna of the Snake Hill shale. Some of these, as the Deep Kill and Normanskill seas, had also connection with the Pacific ocean.

LATER PALEOZOIC HISTORY

Withdrawal of marine waters from the Saratoga region followed the deposit of the Indian Ladder shales and for the latter part of the Ordovician period the region was above water. Then followed a time of considerable disturbance and uplift, the so-called Taconic revolution. Along a belt of country east of Saratoga the Ordovician rocks were folded and upturned. About Saratoga this disturbance had no effect beyond giving the region somewhat increased altitude. During the following Paleozoic periods, Silurian, Devonian etc., the region continued its oscillations of level, but the times of depression did not carry the bottoms of the troughs below sea level. Paleozoic rocks younger than the Ordovician, and all Mesozoic rocks, are absent from the western trough. It remained a trough during all this great lapse of time, but it remained above the level of the sea, even when its altitude was the lowest. Silurian and Devonian seas came into southern New York, but probably the waters of none of them covered Saratoga.

Apparently, however, the district remained at low altitude during all this time. No great thickness of Ordovician rocks has been eroded from its surface. These shales of the upper Ordovician are weak rocks and would be readily worn away under conditions of high altitude and free drainage. That they remain in such thickness as they have over so much of the district is demonstrative of small erosion since they were laid down.

It is quite probable that during oscillations which depressed the western trough, continental deposits accumulated in it and were subsequently worn away during the intervening periods of greater altitude. It is also possible that the overthrust shales of the more

easterly troughs may have formerly extended farther west than they do now, and have covered the present exposures of the rocks of the western trough, from which they were afterward worn away. But this does not alter the fact that the Ordovician shales are the last marine deposits known to have been deposited in the region; that the time which has elapsed since the close of the Ordovician is enormously long; and that it seems inconceivable that these shales could remain over so much of the district and in such thickness, if the trough had ever had a high altitude for any considerable length of time.

CLOSING STAGE OF THE PALEOZOIC

It has long been held by geologists that the closing stages of the Paleozoic were, in eastern North America, a time of great earth disturbance. The district was uplifted and tilted and at the same time the rocks were greatly folded and faulted by compressive forces. Folded rocks characterize the Appalachian district from Alabama to New York, and thence northeast to Gaspé.

It is quite certain that widespread uplift and Appalachian folding occurred at this time; but it would seem also that the preliminary stages of the folding, at least, had taken place long before. The sagging troughs of which we have been speaking, separated from one another by tracts of relative uplift, were the initial stages of this folding, which had been in progress all through the Paleozoic, as recently urged by Ulrich.¹

The Paleozoic deposits of the lower Mohawk trough, the Western basin deposits of this report, were for some reason not greatly folded. They lie nearly flat today. They lay either too far west or without the zone of folding; or else the unyielding mass of the Adirondacks, which lay back of them, acted to prevent folding.

Did the thrust faulting which has carried the rocks of the Eastern basin into our district take place at this time, or not till later? We can not positively answer this question as yet; but we are in agreement with Ulrich in thinking that much of it is of later date and possibly very much later.

MESOZOIC HISTORY

During the entire Mesozoic the Saratoga region remained a land area. During the earlier portion of the time certain troughs along the east margin of the Appalachian region subsided and received a

¹Geol. Soc. Am. Bul., 22:436-42.

large thickness of continental deposits. There is no vestige of such deposits in the lower Mohawk trough, and no direct evidence that they were ever deposited there. That a small thickness of such material may have been laid down in the trough at this date is by no means unlikely. The lower Mohawk trough, throughout its history, has had a tendency to sag, as contrasted with the territory east and west of it. It would not be forced or unnatural to assume that it participated somewhat in the sagging tendency which was so prominently manifest in some neighboring troughs to the east and south at this time. But if such deposits were formed here they were in such slight thickness that every vestige of them has since been removed by erosion.

When were the great faults of the eastern Adirondack region formed? And was the faulting wholly done during one single period of disturbance, or has repeated dislocation occurred along them since they were first formed?

The repeated sags of the western trough would tend to form fault breaks along its margins, separating it from the adjacent districts, the Adirondack region on the west for example, whose tendency has been to rise rather than to sag. It is therefore quite possible that faulting began in the district early in the Paleozoic. With every notable succeeding oscillation of level of the region it is highly probable that renewed faulting would take place along the breaks already in existence. Such an oscillation as that which brought the Paleozoic to a close would be sure to be accompanied by renewed movement along the fault planes.

The early Mesozoic rocks of the easterly Appalachian troughs have been greatly faulted since they were laid down. Obviously this faulting must be of later date than the deposition of the rocks. Most probably also this faulting was not confined to the mere troughs of deposit, but affected the adjacent territory also. It seems in the highest degree likely that further faulting occurred in the Champlain region at this time. The faults of the eastern Adirondack region are normal with nearly vertical fault planes, and these certain Mesozoic faults are of similar type.

On the other hand, the great overthrusts which have carried the rocks of the eastern basin west to their present position, covering much of the Schuylerville quadrangle, are faults of an entirely different type. The question arises as to the relative age of the two types of faulting. If the thrust faulting occurred before the normal faulting it would seem that the thrust-faulted territory

should be also sliced by big normal faults. So far as we know, this is not the case. If on the other hand the thrust faulting is of a later date than the normal faulting, the overthrust materials should rest on a floor composed of the rocks of the western basin, these latter cut by normal faults which do not rise into the overlying, overthrust rocks.

We do not as yet possess decisive evidence on these points. Such as we do have, however, seems to indicate that, in the Saratoga region, the bulk of the thrust faulting is of later date than the normal faulting.

Cessation of the continental deposits of early Mesozoic age in the eastern troughs was probably brought about by renewed uplift. Then followed a long period of erosion whose final result was a rather thorough wearing down of the region to a comparatively level plain. Such an erosion plain is called a peneplain; a peneplain of this date was produced quite generally throughout the Appalachian region and eastern Canada, and it is reasonable to assume that it was also produced here.

CENOZOIC HISTORY

At the close of the Mesozoic the region was again uplifted. The low altitude peneplain which had been produced over the Adirondack region was elevated some 1500 feet or more, and rapid erosion of its surface began. Stream valleys were cut down and broadened. It is the depth of the valley cutting below the old peneplain level which enables us to estimate the amount of the uplift. The divides between the valleys, however, have been but little worn down during the time that has passed since the uplift. These divides rise now to uniform levels, the levels of the old peneplain. An observer, standing upon one of these divide summits and looking abroad to the others, receives the impression of standing upon the surface of a plain and has merely to imagine the valleys refilled with material in order to picture the plain as it was at the time of the uplift.

This old peneplained surface is readily made out over most of the Adirondack region. But in the extreme east it seems to fail and the divide summits rise to very discordant levels instead of being uniform. This we take to mean that here renewed slipping along the old faults occurred as a phase of the uplift; that the Champlain trough displayed anew its tendency to sag relative to

the district to the west; that it was uplifted much less than the Adirondacks; and that the difference in amount was made possible by additional faulting, the easterly slices being thrown down relative to those west of them. The old fault scarps had been peneplained, along with the rest of the region. These further movements renewed them, and their prominence today is in part due to this late movement. The McGregor and Hoffman fronts of the Saratoga quadrangle would be much less imposing than they are had it not been for this.

It is by no means unlikely that further westward movement of the eastern basin rocks along the thrust fault planes also took place at this time.

During the first part of the Cenozoic, the Tertiary, minor oscillations of level took place in the region, but we lack the precise knowledge of just when and what they were. The close of the Tertiary was a time of additional uplift, considerably increasing the altitude of the region, not improbably with renewed faulting. Succeeding this the region was invaded by the ice sheets of the glacial period.

PLEISTOCENE HISTORY¹

Judging from the glacial history of other parts of North America, the Saratoga region was probably covered by four or five successive ice sheets, which extended south from Labrador and occupied the territory. It was certainly occupied by two such sheets. Long interglacial periods intervened between these ice sheets. The glaciers interrupted the drainage, eroded the region somewhat, and on retreat left it cumbered with glacial deposits.

There were also oscillations of level during the glacial period, with loss of the initial high altitude. At the time of retreat of the last ice sheet the altitude of the region was lower than at present.

During the slow, northward retreat of the last ice sheet through the Hudson and Champlain valleys, various bodies of standing water occupied parts of the valley, south of the ice. The most southerly of these, and the one of greatest importance in the history of the Saratoga region, is known as Lake Albany. This was a fresh-water lake which extended as far south as Kingston

¹ Two forthcoming reports by Professors Woodworth and Stoller on the Pleistocene of the Schuylerville and Saratoga quadrangles respectively will furnish full treatment of this portion of the geological history of the region.

Plate 20



H. P. Cushing, photo, 1910

Glacial boulder of Little Falls dolomite on the summit of a low drum-lid hill, 3 miles west of Saratoga. The boulder stands on end and from a distance bears a strong resemblance to a monument shaft.

and, at its greatest extent, perhaps as far north as Whitehall. Fine clays were deposited in its waters and huge sand deltas were built along its shores by the streams which flowed into it. The great terraces of clay and sand which occur both east and west of the Hudson on the Saratoga and Schuylerville quadrangles, were laid down in its waters.

Lake Albany was succeeded by Lake Vermont. The latter lay, for the most part, north of the Saratoga region, in which its deposits are of little importance. In the Champlain valley its waters were lower than those of Lake Albany.

When the ice finally melted out of the Champlain valley the altitude was so much lower than now that the whole of the valley, and of the St Lawrence valley up to Lake Ontario, was below sea level and hence became occupied by marine waters. The whole Champlain-Hudson trough, however, was not thus depressed, Woodworth pointing out that the marine level probably did not reach south of Whitehall. Passing down Lake Champlain the marine beaches, and the marine fossils contained in the deposits, are found at steadily higher altitudes going north. At Plattsburg the marine waters reached a level some 300 feet above the present level of the lake. Woodworth does not believe that the trough south of Whitehall was submerged at this time. The trough seems to have oscillated on a pivot, depression at the north being coincident with elevation at the south, and vice versa. The pivotal line lies in the district between Whitehall and Albany. Since the ice vanished, the northern district has been steadily rising, the marine waters have been excluded from the Champlain and the upper St Lawrence valleys, and the St Lawrence estuary now ends at Montreal. This upward movement is likely still continuing. At the same time the lower Hudson valley seems to have been undergoing depression and its estuary lengthening. The Saratoga region is near the pivotal line and probably has been but little affected by these movements.

We can not leave Pleistocene matters without calling attention to one detail, the impressive glacial boulder shown in plate 20. It stands on the summit of a low drumlin, 3 miles due west from Saratoga, and is a conspicuous object. Viewed from a distance it looks like a monument, a simple shaft. It consists of a huge slab of Little Falls dolomite about 15 feet long, stood up on end. Some exfoliation has taken place, due to frost attack, but on the whole it has suffered comparatively little damage from the

weather. For the glacier to leave a block of such shape in such position in such a commanding situation is highly exceptional, and it is one of the most striking objects of the kind that we have had the privilege of becoming acquainted with.

ECONOMIC GEOLOGY

BY H. P. CUSHING

Molding sand. There is a large annual output of molding sand from the general Hudson river region in New York, especially from the vicinity of Albany. The Schuylerville quadrangle makes a considerable contribution to this output, the material coming from near the surface, just underneath the soil. The sand forms part of the deposits of Lake Albany, which cover most of the surface below the 300 foot level on the Schuylerville quadrangle. For foundry purposes a sand must have a certain degree of refractoriness, cohesiveness, and porosity. Durability is also important, as is texture, but sands of considerable difference in size of grain may be used, the coarser for one kind of castings and the finer for another. The cohesiveness results from the sand occurring mixed with a certain percentage of clayey matter.

The deposits of molding sand have no great thickness, running from 8 or 9 inches up to a few feet thick. They commonly pass into worthless sand below. Good natural molding sands are not very common, so that the demand rather exceeds the supply.

Graphite. Mining for graphite has been carried on at two different localities on the Saratoga quadrangle, both of them quite recent projects. The older and larger of the two establishments is situated about 2 miles west of Porter Corners on the fault plane scarp of the Hoffmans fault. The other is 4 miles north of Saratoga Springs, and similarly situated on the McGregor fault plane scarp. The rock is quite similar at the two localities and seems to represent the same horizon in the Grenville series, a horizon in the quartzite formation. At the time of our study only the establishment at Porter Corners, the Empire Graphite Company, was in operation.

The Grenville beds at this locality have a N. 70° E. strike and a dip of from 30° to 50° to the south. The surface beds are soft and badly altered graphite and mica schists. They are quartz-feldspar-graphite and quartz-feldspar-phlogopite rocks, averaging 50 per cent quartz, 30 to 40 per cent of feldspar and the remainder

a varying mixture of graphite and phlogopite with some apatite. The feldspars are so badly altered as to defy exact determination, but in part at least consist of plagioclase, likely oligoclase. Two beds are being utilized, or are capable of utilization, because of high graphite and low mica content. The upper bed, from 10 to 14 feet thick, has been the one chiefly worked up to date. The lower bed is much thinner. They are separated by a four-foot thickness of quartzite and thin limestone. Underneath is a much more solid bed of mica gneiss. The whole overlies massive quartzite and, like all the Grenville of the quadrangle, is more or less involved with the white, garnet-bearing granite which we regard as Laurentian. There has been an irregular output of graphite by this company since 1906, the production being exclusively flake graphite.

Much the same assemblage of rocks is shown at the pit of the Saratoga Graphite Company, but this is a newer enterprise with much less accomplished in the way of exploitation. Similar weak, altered schists are shown, of the same mineralogic make-up as at Porter Corners. We saw no rock so free from mica as are the two beds worked by the Empire company, though further exploration may disclose equally good material. The strike here is N 80° E, and 30° south dip, and the general similarity of the rock association strongly suggests that we are dealing with the same rock horizon.

Stone quarries. Quarries have been opened in several of the formations of the two quadrangles, in the Precambrian granite and trap, in the Little Falls dolomite, the Amsterdam limestone, the Bald Mountain limestone, and the Northumberland volcanic plug.

Laurentian granite. A small quarry has been opened in the Laurentian white granite on the face of the McGregor fault plane scarp, 2 miles north of Saratoga. Like all the granite of the district it contains Grenville material in all stages of absorption. But the quantity of such inclusions of schist is much less here than elsewhere, the granite is massive and solid and of pleasing color, and there seems no reason why it should not make a most excellent structural material for many purposes. The location, however, is unfortunate, the quarry being situated well up the steep slope of the fault plane scarp, rendering cartage difficult and expensive.

Trap. A large quarry has been opened on one of the large diabase dikes where it is crossed by the North Creek branch of

the railroad, 2 miles north of Saratoga. This dike is at least 100 feet wide on the average, and seems a very long one. Its average trend is N 20° E to N 25° E. For three quarters of a mile south of the quarry it can be followed unbroken, and north of the quarry we have picked it up so repeatedly when crossing its probable location as to convince ourselves that it must be the same dike throughout.

The rock is an ordinary diabase, an augite-feldspar-magnetite combination, lacking olivine. It shows everywhere considerable alteration, the feldspars much kaolinized and the augite largely changed to chlorite. These changes do not seem, however, to have seriously impaired the strength and toughness of the rock and should not, in our opinion, much impair its value as a road rock, for which purpose it has been chiefly used. Because of its width and great length this dike is capable of furnishing a large supply of road material. Where worked it is at low altitude and adjacent to a railroad. Its northern extension is less fortunately situated in these respects, and the same is true of the other dikes of trap in the Precambrian. But since the demand for good trap for road-making purposes in New York at the present time is large, and the supply from the dikes in the Adirondack Precambrian is the only available source in the State outside of Rockland county, it would seem as if there was opportunity for some development of the industry in the Saratoga region, owing to the unusual length and width of the dikes.

Dolomite. Two quarries have been opened in the upper beds of the Little Falls dolomite, within the limits of the two quadrangles, one on Maple avenue in the northern edge of Saratoga Springs, and the other a mile south of Wilton, Schuylerville quadrangle. In both cases the quarries are in the upper, light colored, coarsely crystalline beds of the formation. In the Maple avenue quarry a thickness of 22 feet of massive beds is exposed with a dip of about 5° to the southeast. The upper bed is full of chert; some of the lower beds are full of drusy cavities lined with dolomite crystals and containing crystals of clear, transparent quartz. A small fault is well shown in the quarry wall which is of interest because it seems very old. The throw is only 2 feet, but a strip of fault breccia about 6 inches wide was produced, which was subsequently solidly welded up by deposit of calcite from circulating waters, so that the rock is as strong and firm as it is anywhere in the quarry. The quarry is worked only intermittently,

as demand for stone develops. It is used both for structural purposes and for road metal.

In the quarry near Wilton a twelve-foot thickness of similar beds is shown, also with cherts and drusy cavities containing quartz crystals. This quarry was opened chiefly for road metal purposes, and its product has been much used on the State roads of the vicinity. Some misapprehension as to the true nature of the rock exists in the minds of some people, as we frequently heard it referred to as a trap quarry, perhaps with the idea that any rock used on the roads must of necessity be trap. The material should make an acceptable road metal, though by no means so good as good trap.

Between 3 and 4 miles due west of Saratoga four quarries have been opened in the dolomite, on the west side of the Highland Park fault. The horizon in the formation is somewhat uncertain, but is judged to be near the summit, since Amsterdam limestone is the surface rock a short distance away to the south. The beds are massive for the most part, and consist of alternating courses of dark colored, fine grained stone, and lighter beds of coarser grain. At the time of our visit none of these quarries were being worked and we could obtain but little information regarding them. One of them is quite extensive and the stone is likely used both for structural purposes and for crushed stone.

Limestone. Three of the formations of the district have been quarried for limestone, the Hoyt and Amsterdam limestones of the western basin and the Bald Mountain limestone of the eastern basin.

Two quite large quarries have been worked in the Hoyt limestone, the Railroad quarry and the Hoyt quarry, the former 1 mile north and the latter 3 miles west of Saratoga Springs (plates 5 and 2). Neither has been worked for some years, and the earlier working was to supply lime chiefly for local use. The quarries are thus examples of what has happened on a large scale all over northern New York, the passing of local limekilns and the concentration of the lime industry at a few localities determined by favorable location and quantity and purity of the limestone.

The Amsterdam limestone has been quarried at Rowlands Mill and at Rock City Falls. It was burned for lime to some extent and also used for structural purposes and on the roads. At present it is being extensively quarried at Rock City Falls to furnish crushed stone for concrete.

The Bald Mountain limestone has been quarried at Bald mountain and at Middle Falls. On the west face of Bald mountain the steep western limb of the overturned anticline which this limestone forms there, produces a limestone face 100 feet high, which was well adapted to easy and rapid quarrying. The greater part of the material was burned for lime on the spot.

Ruedemann furnishes the following notes on quarries in this limestone noted by him:

The quarry at Middle Falls, which has furnished the fauna, is a small one, showing some 25 feet of heavy bedded limestone quite like that at Bald mountain. The beds are nearly horizontal. The quarry was long ago abandoned, but the material was probably used exclusively for lime.

A half mile west of Middle Falls, on the west bank of Batten kill, at the bend, is a much larger quarry, exposing a thickness of 50 feet of beds, 20 feet of dolomite beneath, and 30 feet of limestone above. The beds are here nearly vertical, with steep dip to west and northeast strike. One and one-fourth miles farther south is another large quarry, and a smaller one yet farther south. The bulk of the material quarried was burned for lime, but the less massive beds were also utilized in structural work. In the report on the first district Mather speaks of the quarries here, which were in active operation at that time.¹

It is some 40 years since this industry lapsed. There is a large quantity of excellent limestone along this belt, and when the available material at Glens Falls approaches exhaustion, a revival of operations here is not unlikely.

Normanskill grits. There are several abandoned quarries in the grit bands of the Normanskill shales in the vicinity of Quaker Springs. These durable sandstones had a wide use all over the region for structural purposes, but the quarries have been idle for some 20 years.

MINERAL WATERS

The district centering at Saratoga Springs has long been famous for its mineral waters, and especially for its very distinctive, highly carbonated, saline waters. There are in addition numerous sulphur springs in the region, which would probably have a wider repute had the other waters not been also present.

The sulphur waters of the region all rise from the black shales (Canajoharie, Normanskill, Snake Hill), and taste strongly of sulphuretted hydrogen, derived no doubt from the decomposition of

¹ Geol. First Dist., p. 403.

the pyrite of these shales. Such waters are of frequent occurrence the world over; nevertheless such a large spring as the "White Sulphur" spring, near the south end of Saratoga lake, would have great notoriety in most districts.

About Saratoga these sulphur waters are plainly not deep-seated waters of any type; they come from no great distance below the surface, and have not reached a depth so great as the base of the shales. So soon as the drill passes through the shales into the dolomite beneath, the carbonated waters are met with, and would surely be mixed with the sulphur waters, had these reached to like depth.

The carbonated waters. There are few problems in geology more difficult than those concerned with the origin of the mineral waters of a specific region. The precise data which can be obtained are always comparatively few, and the problem must be dealt with by indirect methods. In discussing such questions much that is hypothetical creeps into the discussion unawares; and even in regard to certain fundamental matters our information is so far from being precise, that geologists are far from being in agreement concerning them. Certain things in regard to the occurrence and character of the Saratoga carbonated waters have been definitely ascertained and can be definitely set forth; beyond those we enter the realm of uncertainty and can only discuss probabilities or possibilities.

Control of the waters of the Saratoga region has recently passed into the hands of the State of New York, giving an opportunity for definite experimentation on a considerable water supply of unusual character, which has perhaps never before been equalled, and from which definite and certain information of much general interest is sure to come. Prior to this passing of control there had been a period of some 15 years duration of active drilling for mineral water for the purpose of extracting and vending the contained carbonic acid gas. This development took place in the district south and southwest of the village, mostly within a distance of 2 miles from it. A considerable number of wells were drilled, from nearly all of them the waters had to be pumped, and the amount of water so withdrawn annually was very large. Controversial questions arose which resulted in long and complicated litigation, questions such as the source of the waters, quantity of the supply, and underground arrangement of the waters. As an incidental result much detailed information was made public,

In a bulletin recently published by the State Museum, Professor Kemp has discussed in exhaustive fashion many phases of "The Mineral Waters of Saratoga."¹ An historical sketch is given, the known geographic extent of the waters stated, and the composition and character of the waters very fully treated, followed by a presentation of his personal views on the origin of the waters. It is no part of our purpose here to present a review or repetition of this most excellent piece of work, which may be obtained by anyone interested in the matter. But one or two phases of the problem do seem to us to merit additional treatment at this time.

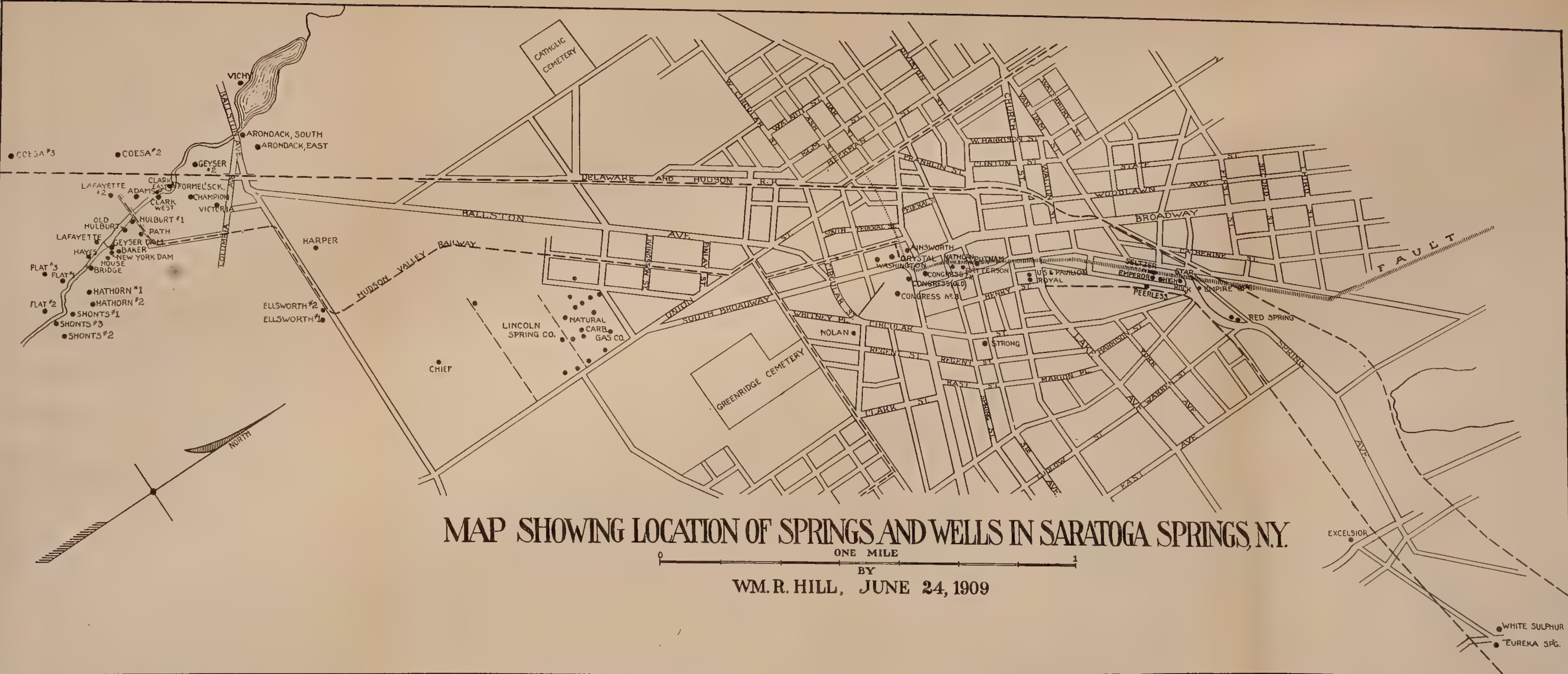
Location. The region of abundant carbonated water centers round Saratoga. The original springs, outflowing at the surface, were chiefly in the village and were few in number, and their multiplication and extension has been due to the use of the drill. There has been much drilling in the village and even more to the south, between Saratoga and Ballston.²

The present springs near or at Saratoga may be conveniently separated into three groups (see accompanying map): (1) the Village group, comprising the line of springs in Saratoga, from the Red spring on the north, to the Congress and Washington on the south; (2) the South Broadway group, the wells of the Natural and Lincoln gas companies, about 1 mile south of the village; (3) the Geysers group, the springs clustered in the vicinity of Coesa creek, about 2 miles southwest of the village. In addition are isolated springs not included in any of the three groups, of which the Gurn spring on the Schuylerville quadrangle, about a mile southeast of Wilton and 6 miles northeast of Saratoga, has the most interest for us.

Geologic occurrence of the waters. The springs in the village all occur on, or in close proximity to, the surface trace of the Saratoga fault. Here are included the original springs, natural outlets of the rock waters. The fault is a trifling one from the standpoint of magnitude, as faults go in the region. Hence the association of the waters with this particular fault must be for a

¹ N. Y. State Mus. Bul. 159.

² See Bulletin 159, pages 7-9, for a more complete discussion of the known springs of the general region. One addition should be made to the list, the Vita spring, near the northeast edge of the Schuylerville quadrangle, 10 miles northeast of the Gurn spring, and *east* of the Hudson. The water is quite like that of the Gurn spring, carbonated, and distinctively of the Saratoga type





reason entirely apart from amount of throw. The significant feature of the fault is that shales are the surface rocks on the downthrow side, and are continuously at the surface to the east for many miles.

Away from the fault the drill discloses carbonated water underground only in territory where shales are the surface rocks, territory to the east of the fault. No doubt, in this shale-covered region, the waters have wider distribution than the drill has yet shown. But there is no reason to believe that there will be any disclosure to conflict with the statement that the water is restricted to shale-covered territory, in which the impervious shales prevent its ascension to the surface; that such territory has its western boundary at the Saratoga fault and that the water can and does make its way to the surface along this fault; and that carbonated water has never been found on the west side of this fault and will never be found there.¹ East of the fault the waters are imprisoned under the shales. The Saratoga fault furnishes the line for escape of the water simply because it happens to be the particular fault which terminates the shales on the west.

The rock which acts as the reservoir for storing the water is the Little Falls dolomite. Invariably the drill discovers it in that rock. Occasionally, owing to local conditions, the drill reached water in the Amsterdam limestone, and was not sent down into the Little Falls beneath. But the evidence is clear in such cases that the water had worked its way up into the limestone from the dolomite along some fissure. Only one well in the whole region, the Hathorn bore, has been carried through the dolomite. This well discovered water in the Potsdam underneath. Unfortunately no sample of this water was saved and analyzed, but Mr Hathorn's statement concerning it is that it was water of the general Saratoga type, but very weakly mineralized; hence the well was sealed far above it and only water from the dolomite admitted. In general, the dolomite is not a porous rock. Certain of its beds have a calcite cement and weather porous; but in the drill cores they all seem solid and impervious, and it seems probable that the water supply in the formation is all contained in cracks and fissures, instead of in porous layers.

¹ The Ainsworth well in Saratoga is a possible exception to the above statement since it may be located a few feet west of the fault line. It is, however, practically on the fault line.

Northward from Saratoga the broad belt of Hudson Valley shale narrows rather rapidly, and north of Fort Edward but little of it remains. In the Champlain valley but a few patches of shales remain, nothing like a continuous cover. Judging by the Saratoga vicinity, such a cover is necessary both to prevent the free escape of the mineral water and to prevent its admixture with overwhelming quantities of surface water. This fact would seem to account for the nonappearance of these carbonated waters to the north.

The rocks of the general region dip to the south, hence the shale cover thickens southward and the mineral waters, if present, are at a steadily increasing depth below the surface. In the village the driller reported for the Star spring bore, only a short distance east of the fault line, that the bottom of the shale was 100 feet below ground, 38 feet drift, 62 feet shale, then limestone. The Natural Company wells on South Broadway show an average of 140 feet of drift and 50 to 100 feet of shale before reaching limestone. At the Geysers the limestone is still deeper. The Hathorn No. 2 well reported 23 feet of drift and 432 feet of shale above the limestone. At Ballston the shale is 200 feet thicker than this, and the limestone correspondingly deeper. The waters then extend to the south of Saratoga under the shales, but the depth of drilling necessary to reach them steadily increases in that direction, and away from the Saratoga vicinity they do not come to the surface naturally. They likewise extend probably far to the east under the thickening shale cover.

It is by no means unlikely that to the south of Saratoga, the water may extend to the west of the Saratoga fault. As has been previously stated, the course of this particular fault south of Saratoga is conjectural, but on the assumption that it runs down to Ballston, as provisionally mapped, it would be quite possible for the waters to pass beyond it and appear west of it. About Ballston shales are the surface rocks on both sides of the fault, with the Little Falls dolomite below ground on each side under a protecting shale cover. Along the south margin of the Saratoga quadrangle the shales extend entirely across the sheet from east to west, the southerly dip of the rocks giving rise to shales at the surface in each of the successive fault strips. The diagram, figure 16, will explain the assumed course of the underground water, better than can be done verbally.

It is possible to account for the presence of these waters, held imprisoned beneath the shales, in one of two ways. They may

be regarded as deep-seated waters which have arisen from depth along the line of the Saratoga fault and spread from the fault plane into the dolomite, in which rock they migrated away from the fault plane and down the dip, to the east and south, thus changing from ascending to descending waters; or they may be regarded as having come from some source to the east and as having used the dolomite as their route toward the west, coming up the dip of the rock as ascending waters, the head supplied from the hills east of the Hudson. Until the Saratoga fault is reached the water is confined to the dolomite by the impervious cover of

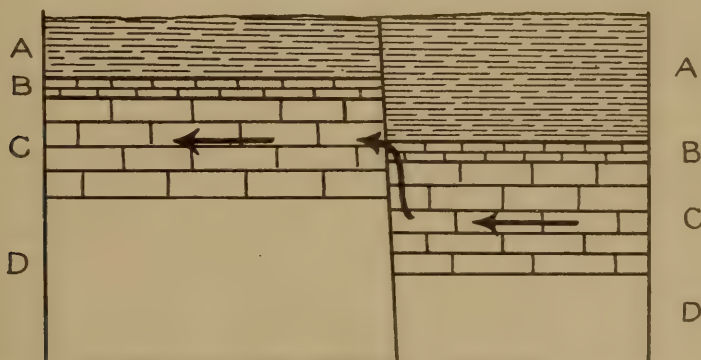


Fig. 16 Diagram of the supposed extension of the Saratoga fault at Ballston. The arrows indicate the course taken by the underground water which comes from the east through the dolomite, rises along the fault fracture to the level of the dolomite on the west (upthrow) side, and passes into that toward the west, the shales preventing it from coming all the way to the surface.

A = Canajoharie shale, B = Amsterdam limestone, C = Little Falls dolomite
D = Hoyt, Theresa and Potsdam formations in order.

overlying shale, and at the fault the first opportunity to escape to the surface is given. On this view the waters do not ascend from any great depth along the fault, but merely follow it to the surface from their fissures in the dolomite, below ground on the east side of the fault. In our opinion this latter view represents the true state of the case. Ruedemann was the first to see this clearly, his opinion being based on his structural work in the district of overthrusting east of the Hudson. He has prepared a statement of his views, which appear on page 165 of this bulletin. We are in cordial agreement with his reasoning as there outlined. As previously stated, we think the lack of carbonated waters to the

north is readily explained by the lack of the shale cover, so that any possible carbonated water in the region would become diluted and swamped in the general mass of the ground water, which would readily work its way downward into the rocks of the region and drown out the other water. Of his theory in regard to the origin of the carbon dioxid, we shall have more to say shortly.

The shale cover. It is not pretended that the shale cover is absolutely impervious to water; in fact it is known not to be. In places, especially near its thinned, western edge, where less than 100 feet thick, springs of carbonated water broke through it, arising probably along joint cracks. Such cracks are present in all shales, especially near the ground surface, and are present here. A few furnished channels for rising carbonated waters. Enough of them became filled with ground water to transmit the general ground water head to the carbonated rock waters beneath, thus influencing their direction of movement. The matter is perhaps best illustrated by a discussion of the conditions at the South Broadway wells.

Inspection of the topographic map will show that the ground occupied by the Natural and Lincoln companies a mile south of the village along South Broadway, is relatively elevated as compared with the line of occurrence of the springs in the village, or as compared with the springs along Coesa creek. The levels near South Broadway are between 310 and 320 feet, with a summit of something over 320 feet elevation just east of South Broadway. In the village the well heads have a general elevation of 280 feet, which is also the average elevation along Coesa creek. From South Broadway the ground level falls both toward the village and toward Coesa creek (the normal *ground water* level should also fall toward each from a high point on South Broadway), and if this ground water head is transmitted down through the shales along occasional cracks into the waters contained in the dolomite, as seems highly probable, the tendency in these carbonated waters would be also to move away from the South Broadway region toward the village and toward Coesa creek. That is, the water pressures would lend themselves to such a movement of the underground waters and would oppose a contrary movement. If the water head on South Broadway were interfered with and lowered by any cause, this natural flow would be correspondingly weakened and the water levels in the village and along the east side of Coesa creek sympathetically lowered.

The generalized section of the rocks above the Little Falls dolomite shown in the Natural Company's wells on South Broadway is as follows:

140 feet Drift	{	Soil and gray sand	25 feet
		Quicksand	45 feet
		Clay	20 feet
		Sand and gravel	50 feet
118 feet Canajoharie shale	{	Shale	75 feet
		Alternating shale and limestone	43 feet

36 feet Amsterdam limestone

Little Falls dolomite

The lowermost drift deposit at the locality is a heavy bed of porous sand and gravel, capped by a twenty-foot thickness of quite impervious Albany clay. When first entered by the drill these lower sands were full of carbonated water, which had got into the sand because of one or more natural springs coming up through the shales and which had been retained there by the cover of impervious clay. There was here a local reservoir of carbonated water at a horizon 150 feet or more above the water in the dolomite. At an early date in the history of the operations of the Natural company this upper reservoir was pumped out and so remained. When full it served to transmit the pressures of the ground waters in the upper sands down to the rock waters beneath; when exhausted of water the hydrostatic column was interrupted and this pressure no longer transmitted, with the result that the normal water head was lost, what amounted to a great cone of depression was produced, and the water levels in the village and on the east side of Coesa creek were affected.

The presence of original carbonated water in this sand we take to demonstrate the presence of outlets for the water in the shales below. The carbonated water came up through the shales and filled the sand reservoir under the clay.

Since pumping ceased all over the district, as it passed under State control, this pumped out reservoir in the sand has been slowly refilling. When such refilling shall be complete and the old ground water head thus restored, we look to see a demonstration of its effect upon the water levels in the lower grounds.

The waters in the dolomite are no doubt following crevices for

the most part. There must be a host of these, and the connections between the different water-bearing crevices must vary greatly in character. Some must be very direct and others extremely indirect. So long as they were controlled by the same general hydrostatic head they would be expected to show close sympathy in action, whether the connection were direct or indirect. With the loss of this general head, controlling the water pressures in all the crevices, this close sympathy of action would no longer obtain. Active pumping of a well might quickly and notably affect the water level of a neighboring well, and not at all affect another well equally near to the first but in a different direction from it. In the first case the underground connections would be fairly direct; in the second case very indirect; but under the circumstances the conclusion that there was no underground connection whatever between the two wells, might not be justified at all.

Have the waters a common source? The carbonated waters of the Saratoga region are peculiar. The abundance of carbon dioxid, of sodium chlorid, and of calcium, magnesium and sodium bicarbonates, and the almost entire lack of sulphates, gives them a character which is possessed by few other natural waters the world over. Taken together with their restricted distribution, this leads irresistibly to the conclusion that they have a common source. They distinctly impress us as mixed waters, waters which have not obtained all their dissolved mineral matter at the same time and place and which, probably in the latter stages of their underground journey, have become diluted in varying degree with fresh, surface waters. The varying degree of mineralization of the waters of the different springs, when compared with one another, is most simply and naturally accounted for in this way. The statement which has been made in regard to some of the pumped wells, that unusually prolonged and vigorous pumping of a well results in bringing to the surface brine of increased strength, seems to us to point to the same thing. Under these circumstances less dilution with fresher surface waters takes place than is normal for the particular well.

By a common source we mean that the original mineralization of the waters takes place in a specific underground area of unknown extent, owing to specific chemical reactions of unknown nature, and that from this area the waters follow a definite route to the surface, no doubt undergoing further mineralization on their way. Our conception of the route is that from a deep-seated

source to the east the waters follow the upward inclines of the thrust planes and of the beds of dolomite, which eventually lead them to the surface in the Saratoga region; that in the dolomite the waters make their way along a multitude of fissures or cracks in the rocks, constituting a great network of channels which are all connected when considered at large, but which locally may, or may not, be closely connected.

Summary. We hold it to be demonstrated that the Saratoga carbonated waters, as they exist underground, are confined to the district which has a shale cover, underneath which they are held imprisoned in the Little Falls dolomite; and that the water originally found escape, to a limited amount, along the Saratoga fault and through the shales near their thinned western edge. Certain of these outlets were known, but there were also others in unknown number hidden under cover of overlying glacial drift. We hold it to be in the highest degree probable that the waters are mixed waters, that they have in part a deep-seated source, and that they come from the east, following up the thrust planes and up the dip of the dolomite beds, utilizing fractures in the dolomite as their channels. When their path is blocked by a normal fault, they utilize it to rise to the level of the dolomite on the upthrow or west side, and then reenter the dolomite. When the particular fault which terminates the shales on the west is reached, the waters rise to the surface along it wherever the ground levels permit. The village springs and the Gurn spring are located on such a fault. The Vita spring and the springs along Coesa creek rise through the shales, quite possibly along a fault, though the fault has not been demonstrated in either case.

When we pass from these matters to those concerned with the amount and permanence of the water supply, and to the question of the origin of the waters, we are dealing with questions of quite another sort, questions regarding which wide differences of opinion prevail, and concerning which we can obtain little or no direct information.

The water supply. Below ground the manufacture of this mineral water either has, or has not, ceased. It is still being manufactured, or it is not. If not, then we are dealing with a stored water supply of definite amount, which can be pumped out and exhausted, just as underground stocks of petroleum and of natural gas become exhausted. It seems to us unlikely that this is a case of the kind. Springs have been flowing at Saratoga ever since the region became known, and for an unknown length of

time prior to that, no doubt a very long time. There is much natural escape and there are too many outlets to allow us to believe that the original supply, however large, could have withstood such a steady drain on its resources. We are rather forced to the belief that we are dealing with a great, underground water circulation in natural equilibrium, inflow and outflow being equal, and that the rate of natural outflow measures for us the rate of manufacture and of inflow. If this be true, there is not the same danger of exhaustion of the supply that there would be in the other case. But this is a very different thing from saying that the supply is unlimited and can be drawn on indefinitely at a rate much in excess of the normal circulation.

The origin of the water. Any discussion of this problem must of necessity be almost wholly theoretical. Our lack of definite knowledge of too many of the factors is too great to permit it to be otherwise. We refer to it at all here only because Professor Kemp has exhaustively discussed the problem in Bulletin 159, and because we wish briefly to consider one or two points made in that discussion. A brief synopsis of his argument must precede.

Kemp gives a very exhaustive discussion of the composition of the Saratoga waters. Omitting minor constituents, they are characterized by high content of chlorids and bicarbonates of sodium, calcium and magnesium, high content of uncombined carbon dioxid, and extremely small content of sulphates. He distinguishes three divisions of underground water from the standpoint of origin, meteoric waters derived from the rainfall, magmatic waters derived from cooling igneous rocks, and connate waters, generally marine waters buried in the rocks at the time of deposit and retained in them. Then by a process of elimination he rules out connate waters as a possible contributing source for the Saratoga waters, in whole or part, because they lack sulphates in solution. He dismisses meteoric waters as a possible source of the carbon dioxid and the chlorids, because we know of no chemical method by which they might be produced in such waters in the Saratoga region; and he finally concludes that these constituents are therefore likely of magmatic origin. His summing up is as follows:

The explanation which appeals most strongly to the writer is that the carbonic acid gas, the chlorids, bromids, iodids, fluorids and sodium carbonate are deep-seated. The sodium carbonate might in part or in whole be dissolved from the feldspars in the old crystalline rocks. The carbonated waters take on calcium and magnesium carbonates from the limestones encountered in their upward journey, more especially from the Little Falls dolomite.

Our purpose here is not at all to express disagreement with these views of Kemp. We are not sure that we do disagree with them. Kemp has made an important contribution to the geology of the mineral waters of the region, by elaborating a definite theory concerning their origin. We simply wish to emphasize the difficulty and complexity of the subject, and our lack of definite data regarding it, and to suggest alternative views in one or two respects.

We feel quite confident, in the first place, that the volcanic knob at Northumberland is no evidence whatever of underground igneous action, in the general region, of sufficient recency to have any bearing on the question of the existence of present-day juvenile waters underground. It does not show that such water does not exist. But we think that the evidence for the presence of such water is wholly independent of the presence of the plug, and is neither strengthened nor weakened by it.

We quite agree that the carbon dioxid and the chlorids have a deep-seated source, but we think Ruedemann's suggestion as to the possibility of the carbon dioxid arising from deep-seated metamorphism of the rocks is quite worthy of consideration as an alternative hypothesis to the juvenile one.

The tangential pressures which gave rise to the overthrusts may have operated up to very recent times and may still be in operation. They must aid in metamorphosing deeply buried sediments. In such sediments there is generally much lime, partly as beds of pure limestone, partly in impure limestones, calcareous shales and calcareous sandstones. In regions of metamorphosed sediments it is the common experience to find the limestone formations converted to marble and retaining all their original carbon dioxid. The impure limestones and the calcareous shales, on the contrary, recrystallize to schists containing little or no calcium carbonate, but much calcium silicate in such minerals as pyroxenes, amphiboles, garnets etc., and we must assume that the calcium has been recombined and carbon dioxid set free. Kemp lists this process as one of the methods of the manufacture of uncombined carbon dioxid below ground, and states its possible applicability to the Saratoga region, but dismisses it as, to his mind, less likely than an igneous source. But when combined with Ruedemann's theory of the eastern source of the water it seems to us to take on greater probability and to be worth considering as a source of the gas.

Nor do we feel at all certain that connate waters are to be entirely ruled out of the question. The lack of sulphates in the

Saratoga waters is a very real difficulty. But the possibility of the sulphates having been precipitated somewhere along the long route of water ascent, may be suggested as an alternative view. Such a reaction as that investigated by Hilgard some years ago, a solution of sodium sulphate in presence of free carbonic acid dissolving calcium carbonate, with formation of sodium carbonate and precipitation of calcium sulphate (gypsum), suggests what may conceivably have happened.¹ That connate waters of marine derivation must have originally contained sulphates does not seem to us open to question; but it does not necessarily follow that, on admixture with other waters, the sulphates should persist in solution. We do not urge this as a probability but merely as a possibility. It does not seem to us proven that the Saratoga waters may not receive a contribution from a connate source.

These observations are in no sense a criticism of Kemp's theory, but merely intended to emphasize the difficulty and complexity of the subject. The two main difficulties in the way of unqualified acceptance of the juvenile origin of the Saratoga waters are that they are not thermal waters, and that we have no direct evidence of igneous action of any recency in the vicinity, or anywhere else in the eastern United States. It is the latter fact particularly that makes us cautious and causes us to reserve judgment and leads to the suggestion of other possibilities. The theory is not condemned by us; we regard it as very likely true. But we do not as yet see our way to its unreserved acceptance.

A paragraph at the close of Dr F. W. Clarke's discussion of Mineral Wells and Springs so well expresses our state of mind that we conclude by quoting it.²

And yet, notwithstanding all that has been written on the subject, the controversy over the genesis of hot springs is not closed. What is the origin of the carbon dioxid with which so many mineral waters are heavily charged? In some instances, doubtless, it is derived from the decomposition of limestones, but in others this explanation can not suffice. Here and there it may be, to use Suess's expression, "juvenile," and evidence of the deep-seated origin of a spring. Again, whence comes the sodium chlorid of waters that flow from sources where it could not have been previously laid down? These questions, and others like them, still await satisfactory answers.

¹Am. Jour. Sci., 4th ser., 1896, 2:100.

²U. S. Geol. Surv., Bul. 491, p. 203.

RELATIONS OF THE SARATOGA MINERAL SPRINGS TO THE
STRUCTURE OF THE SHALE BELT OF THE UPPER HUDSON
VALLEY.

BY R. RUEDEMANN

The study of the shale belt of the Saratoga and Schuylerville quadrangles by the writer has brought out certain structural features which appear to explain the accumulation of the mineral waters in the Saratoga region.

The salient facts in the distribution of the mineral water for the discussion here presented are : (1) the mineral springs are distributed in a belt extending in a northeast-southwest direction, from the Gurn spring to Ballston Spa and farther south (Albany?) ; (2) the waters come up in connection with or near a fault line, extending in this direction ; (3) the water does not occur west of this fault line, but is found far to the east of it (Quaker spring and Vita spring) ; (4) it is stored in a series of limestone, dolomite and sandstone formations underlying a shale formaton.

The investigations of the writer have now shown that the shales forming the surface rocks east from the springs fault belong to two entirely different series or sets of formations which were deposited in two separate basins.

The western set begins on top with the Canajoharie shale. This is underlain by the Glens Falls and Amsterdam limestones, the Hoyt limestone, Little Falls dolomite and Potsdam sandstone, the latter resting on Precambrian rocks, mostly gneiss.

This western series, which sinks in one or two step faults from the Precambrian area of the Adirondacks to the level of the Saratoga plain, is but little disturbed and the beds are but little tilted and not folded. It continues eastward to an unknown extent, which, however, must be considerable since only the western edge of the old basin is now exposed on the surface. Undoubtedly it extends as far as the eastern hill region, as indicated in sections.

Only 3 miles east of Saratoga an entirely different set of formations begins to appear on the surface. In this set most formations are represented by shale, namely, the Trenton by the Snake Hill shale, the Chazy by Normanskill shale, the Beekmantown by Bald Mountain limestone (thin), Deep Kill shales (thick) and Schaghticoke shale, and the Cambrian by the Georgian shales, slates, limestones and quartzites. This set of formations, as their lithologic character and faunas show, has been formed in another more

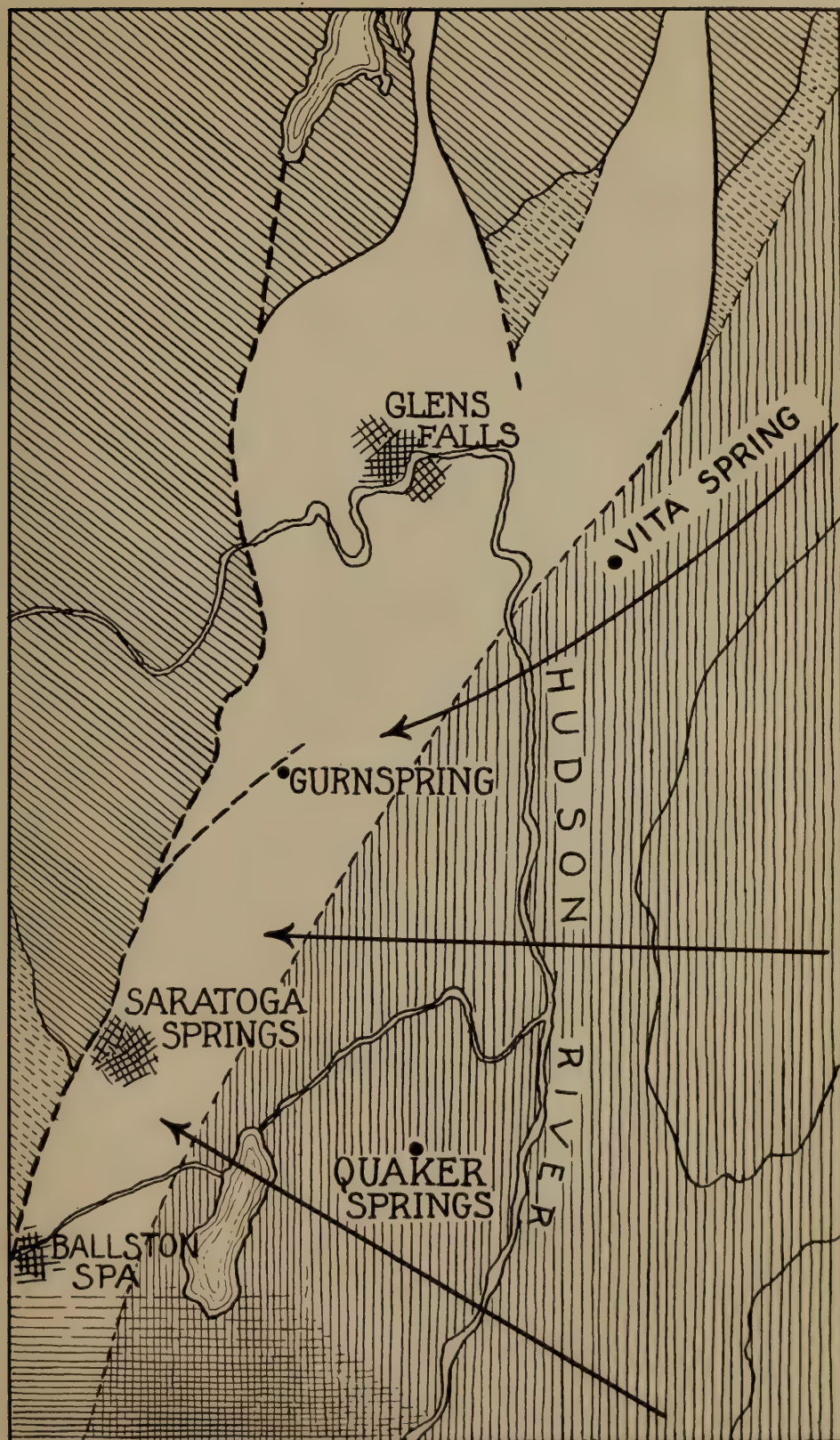
easterly basin. The diastrophic movements, which raised the Green and Taconic mountains, have not only intensely crumpled and folded this entire mass, but also shoved it a great distance westward until it has overridden the western set of formations to within a few miles of Saratoga.

The combined effect of this great overthrusting of the eastern shale masses on the western set of formations has evidently been that the limestones of the latter have been buried under an immense mass of shales. At Mechanicville, for instance, only a few miles from the western edge of this shale mass, a well was sunk 1400 feet through these shales without reaching their bottom. Further, this mass undoubtedly forced the western set of rocks downward, a process which was helped by step faults such as occur at Saratoga farther west.

We thus get a set of limestone and sandstone formations that descends gradually eastward to greater and greater depths, becoming all the time buried under greater masses of impervious shales. The mineral waters, which for good reasons are considered as coming from the east, find thus a channel in the jointed and broken limestones and porous sandstones, gradually rising westward until they strike the Precambrian block at Saratoga, where they rise along the Spring fault and through the relatively thin shale cover to the surface from the storage basin that is formed in the fault block upon which the eastern part of Saratoga Springs stands. This underground course of the water is indicated in the sections on plate of sections by the blue line.

The pressure necessary to bring the waters on the long journey from the east through this underground channel is probably supplied through the head obtained from the mountain regions in the east.

It is not intended to explain the origin of the carbonated mineral waters by the structure of this basin, although the possibility may be suggested that the limestones may in their eastward descent reach such depths that they may become subject to metamorphism through which the carbonic acid and some of the salts become dissociated. At any rate, the known regional metamorphism of the rocks of the eastern trough in the Taconic-Green mountain regions is a fact worth remembering in this connection, and the



Precambrian rocks
out-cropping on
surface



Precambrian rocks
near surface

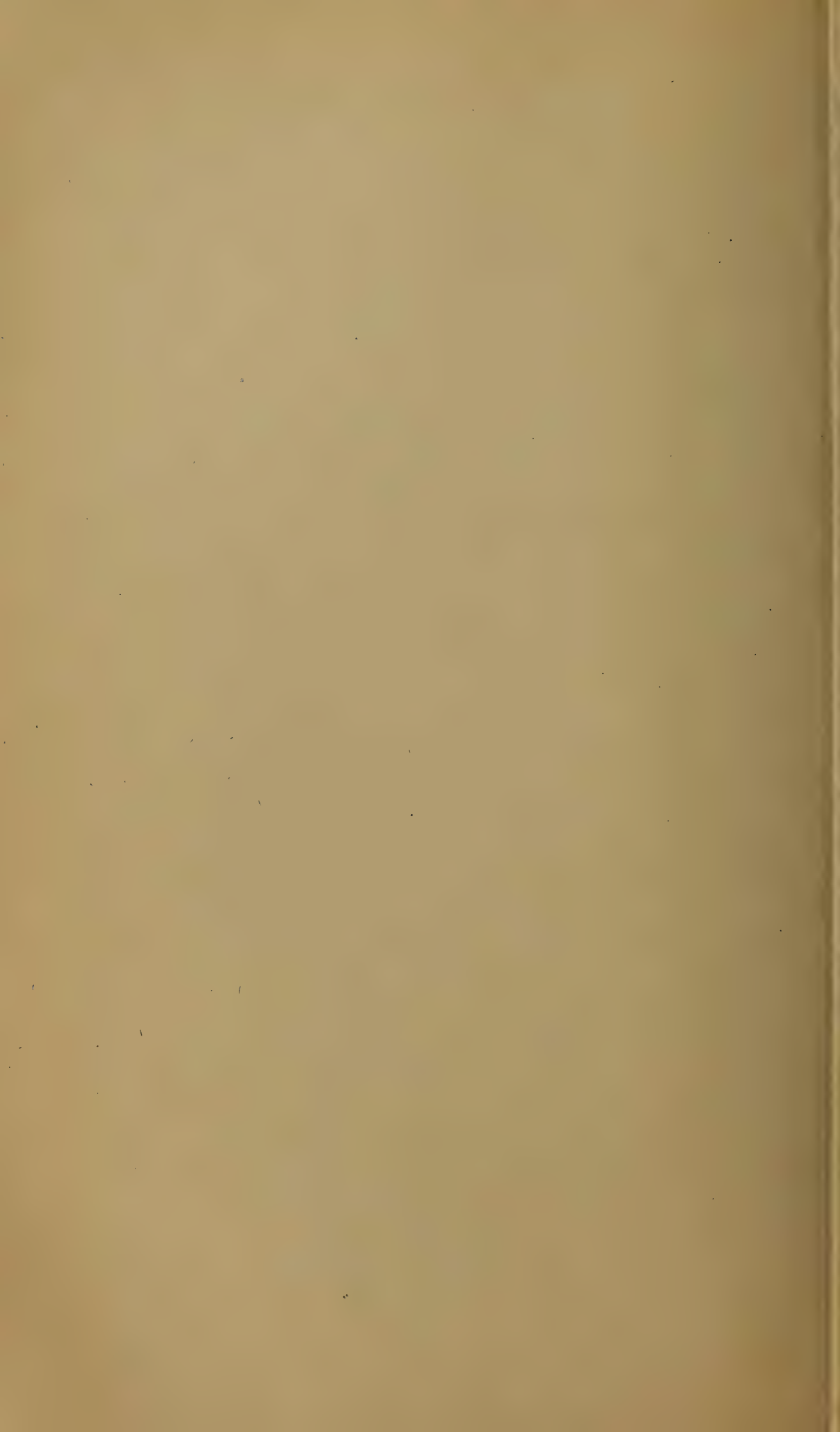


Folded and over-
thrusted rocks of
eastern trough



Canajoharie shale
rapidly thickening
south

Fig. 17 Diagram to show the blocking of the mineral waters in the Saratoga region by fault blocks of Precambrian rocks in the north and west and the thickening cover of shales at the east and south.



possibility of the continuation to the present time of these processes that metamorphose the shales, limestone and sandstones into schists and gneisses in the depths of the mountains is not at all disproved. At the same time it is also possible that these same limestones and sandstones come within the influence of deep-seated, still heated igneous rocks, thence deriving their carbonic acid, and at the same time that they gather "connate" waters (original sea water deposited with the rocks) from a large area and held in the depths, to which they descend, through the thick covering masses of shales.

One naturally asks here why these waters only come up in the Gurnspring-Saratoga-Ballston belt, a stretch altogether not more than about 12 miles long. The geologic structure of the region is responsible for this phenomenon (see diagram, text fig. 17).

South of Ballston the shales again thicken rapidly on account of the southward dip of the beds, until at Schenectady they reach no doubt more than 3000 feet in thickness, thus shutting the waters off from the surface to the south of the Saratoga mineral springs region. Northward of this region the structural relations are not yet well understood and the reasons for the absence of the springs not apparent. At Glens Falls the "Trenton" and Black River limestones come again to the surface but without bringing any mineral water. This outcrop is apparently the southern spur of a fault block. It probably fails to intercept the mineral waters coming from the east because it lies west of another large fault, which is indicated by the Fort Ann spur of Precambrian rocks and which extends close to or into the crumpled shales of the eastern basin, thus shutting off the mineral waters from access to more western regions or to the surface altogether. We have seen before that the Precambrian rocks west of the Spring fault form a barrier for the waters in that direction and that the thick masses of shales east of the area serve there as a competent cover. The Spring belt is thus shut in on all four sides by either thick masses of shales (east and south) or barriers of Precambrian rocks (west and north) and in the belt itself the waters are brought nearest to the surface in following the routes of least resistance.

CONTROL OF DEVELOPMENT AND HISTORY OF SARATOGA REGION BY THE GEOLOGY

BY R. RUEDEMANN

Saratoga and Schuylerville (the original Saratoga) quadrangles are historic ground. The battles of Bemis Heights and Saratoga (present Schuylerville) which have been cited among the fifteen decisive battles in the history of the world, were fought on this ground, and these, more than any other events of the Revolutionary War, the people of the United States have to thank for their freedom.

Any one who studies this region with an interest both for its fascinating history and its geology, can not fail to be impressed by the close relationship between the course of the historic events and the geology of the region. In view of the especial interest attaching to anything connected with the history of Saratoga, it may therefore be well briefly to point out the influence of the geology upon (1) the development of the region, and (2) the course of the struggle between the American and British armies.

The Hudson river formed the natural highway through this country not only for the Indians but also throughout colonial history. The early Dutch settlers followed this stream into the northern woods and first settled the fertile bottom lands and then the edge of the rich land on top of the clay banks laid down in Lake Albany. When Burgoyne pressed into the country he found only this thin first line of settlements, while back of the river on both sides there extended the primeval forests. Here the Dutch reached the northern limit of their settlements and gave names to the Moses kill, Snook kill, Batten kill and Fish kill. Later, New England pioneers came from the east through the mountain passes provided by the Batten kill.

While the fertile clay plains and bottom lands along the river attracted the first farming population, another geologic influence created a second center of settlement in the western, less fertile, sand region of these quadrangles. This was the mineral springs that issued at the foot of the fault scarp at Saratoga and which were already highly valued by the Indians for their healing qualities. Because of them Saratoga Springs, in the middle of the former century, became the foremost summer resort of the continent and the largest town on the two quadrangles, and on their account the railroad trunk line from the Hudson river through

the Champlain valley to the St Lawrence, the Delaware & Hudson Railroad, does not follow the Hudson river to Fort Edward as one would expect, but leaves it at Mechanicville to swing far to the west. Thus again the influence of the faults which bring up the mineral waters of Saratoga is strongly felt in the distribution of the population of the quadrangles and the direction of the principal railroad.

A third geologic agent which controls the distribution of the settlements and which is constantly growing in importance is the presence of rapids and waterfalls in the rivers and brooks. These are due to two causes in the region, first, the greater erosive power of the Hudson river over that of its tributaries on both sides, whereby the latter flow in "hanging valleys" and are forced to reach the level of the river along a series of falls and rapids in their lowest course; and, second, the rejuvenation of the rivers by the glacial period, in consequence of which in their new, immature courses they frequently meet ridges of harder rock protruding into the glacial deposits from the irregular preglacial surface, and in such places are dammed up and form falls or rapids. Thus Schuylerville and Victory Mills grew up where Fish creek falls into the deeper Hudson valley; Ballston Spa where the Kayaderosseras creek falls into the old preglacial fault depression of the Saratoga fault; Thomson and Fort Miller where the Hudson river plunges over ridges of shales, chert and grit that block its way. Likewise Gansevoort is located where the Snook kill strikes a line of anticlinal ridges and overthrusts in the Canajoharie shale and supplies water power by a waterfall, and Clark Mills where the Batten kill crosses a ridge of harder Normanskill rocks; Middle Falls where it is held up and falls over the Bald Mountain limestone, and Greenwich where the olive grits of the Georgian formations force the Batten kill to form rapids and supply water power. It is thus seen that every village in the shale belt is located where water power is produced by the geologic structure of the region.

Equally interesting with the control of the settling of this region by its geology is that of the events of the battles of Saratoga by the same agency.

Burgoyne had two routes to reach the Hudson river and thereby Albany, his objective point; namely, first, the deep depression extending from Whitehall to Fort Edward and caused largely by the downfaulting of the Ordovician rocks at the eastern base of the Adirondacks and, second, the fault basin of Lake George. He

selected the former and entered the swamp region of Wood creek, following this creek with its immature swampy drainage up toward the Hudson. Here it was extremely easy to impede his progress by cutting trees and throwing them across the road, an opportunity of which the Americans made the fullest use. Burgoyne wasted months of valuable time and his best energy and provisions in these swamps of glacial origin. When he finally reached the Hudson he followed it on the east side until he found the place where at Thomson the river falls over a ridge of harder Normanskill shale below which a bridge could be easily built. After crossing he was again forced to the river bank by the only road available, while deep ravines cut into the thick clays of Lake Albany made excellent opportunity for a defensive position for the American army. Such a position was selected at Bemis Heights.

On the other side of the river towers Willard mountain, an erosion remnant due to the hardness of the grits and cherts of Normanskill age that compose the syncline. From this bold mountain every movement of the British army could be easily seen by the patriot Willard and signalled to General Gates.

After his defeat, Burgoyne retreated leisurely and sullenly up the river. Hessian officers advised him to leave his cannon and baggage behind and save the army by a forced retreat by way of Lake George, but the obstinate though brave general decided to return by the crossing at Thomson, allowing by his slow and undecided action the Americans to overtake him and, in using the peculiarly favorable topography of the locality, which is due to its remarkable geology, to prepare a trap for him. The most important feature of this topography is that just above the Thomson crossing a volcanic rock, known as the Northumberland volcanic plug, juts out prominently toward the river, so that it has complete command of the crossing and at the same time prevents an army from passing under it at the west bank of the river. This important strategic point was occupied by Colonel Stark. It, and Fellows's batteries which could be advantageously placed on the bluffs of Albany clay on the opposite bank of the river, were, with Morgan's sharpshooters in the woods to the west of the army, the principal means of forcing Burgoyne to surrender. Thus we see that the peculiar combination of a ford over a shale ridge, a volcanic rock close by and bluffs of clay aided greatly in bringing about the decisive victory of Saratoga.

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New York State Museum

JOHN M. CLARKE, Director

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Director's annual reports 1904-date.

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1906.	186p. 41pl. 25c.	1911.	218p. 49pl. 50c.	
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These reports cover the reports of the State Geologist and of the State Paleontologist. Bound also with the museum reports of which they form a part.

Geologist's annual reports 1881-date. Rep'ts 1, 3-13, 17-date, 8vo; 2, 14-16, 4to.

In 1898 the paleontologic work of the State was made distinct from the geologic and was reported separately from 1899-1903. The two departments were reunited in 1904, and are now reported in the Director's report.

The annual reports of the original Natural History Survey, 1837-41, are out of print.

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Botanist's annual reports 1867-date.

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Separate reports for 1871-74, 1876, 1888-98 are out of print. Report for 1899 may be had for 20c; 1900 for 50c. Since 1901 these reports have been issued as bulletins.

Descriptions and illustrations of edible, poisonous and unwholesome fungi of New York have also been published in volumes 1 and 3 of the 48th (1894) museum report and in volume 1 of the 49th (1895), 51st (1897), 52d (1898), 54th (1900), 55th (1901), in volume 4 of the 56th (1902), in volume 2 of the 57th (1903), in volume 4 of the 58th (1904), in volume 2 of the 59th (1905), in volume 1 of the 60th (1906), in volume 2 of the 61st (1907), 62d (1908), 63d (1909), 64th (1910), 65th (1911) reports. The descriptions and illustrations of edible and unwholesome species contained in the 49th, 51st and 52d reports have been revised and rearranged, and, combined with others more recently prepared, constitute Museum Memoir 4.

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3 Economic Geology	60 Zoology	117 Archeology
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- v. 1 Soils of the State, Their Composition and Distribution. 11 + 371p. 21pl. 1846.

- v. 2 Analysis of Soils, Plants, Cereals, etc. 8 + 343 + 46p. 42pl. 1849.
With hand-colored plates.

- v. 3 Fruits, etc. 8 + 340p. 1851.

- v. 4 Plates to accompany v. 3. 95pl. 1851.
Hand-colored.

- v. 5 Insects Injurious to Agriculture. 8 + 272p. 50pl. 1854.
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DIVISION 6 PALEONTOLOGY. Hall, James. Palaeontology of New York. 8v. il. pl. sq. 4to. Albany 1847-94. *Bound in cloth.*

- v. 1 Organic Remains of the Lower Division of the New York System. 23 + 338p. 99pl. 1847. *Out of print.*

- v. 2 Organic Remains of Lower Middle Division of the New York System. 8 + 362p. 104pl. 1852. *Out of print.*

- v. 3 Organic Remains of the Lower Helderberg Group and the Oriskany Sandstone. pt 1, text. 12 + 532p. 1859. [\$3.50]
— pt 2. 142pl. 1861. [\$2.50]

- v. 4 Fossil Brachiopoda of the Upper Helderberg, Hamilton, Portage and Chemung Groups. 11 + 1 + 428p. 69pl. 1867. \$2.50.

- v. 5 pt 1 Lamellibranchiata 1. Monomyaria of the Upper Helderbergs, Hamilton and Chemung Groups. 18 + 268p. 45pl. 1884. \$2.50.

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- pt 2 Gasteropoda, Pteropoda and Cephalopoda of the Upper Helderberg, Hamilton, Portage and Chemung Groups. 2v. 1879. v. 1, text. 15 + 492p.; v. 2. 120pl. \$2.50 for 2 v.

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- & Clarke, John M. v. 8 pt 2 Paleozoic Brachiopoda. 16 + 394p. 64pl. 1894. \$2.50.

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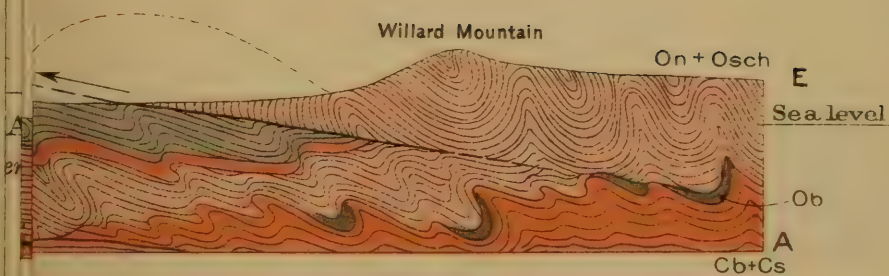
Brief outline of State Museum work in paleontology under heads: Definition; Relation to biology; Relation to stratigraphy; History of paleontology in New York.

Guide to Excursions in the Fossiliferous Rocks of New York. 124p. 1899.
Out of print.

Itineraries of 32 trips covering nearly the entire series of Paleozoic rocks, prepared specially for the use of teachers and students desiring to acquaint themselves more intimately with the classic rocks of this State.

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- Entomology. 16p. 1899. *Out of print.*
 Economic Geology. 44p. 1904. Free.
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Geologic maps. Merrill, F. J. H. Economic and Geologic Map of the State of New York: issued as part of Museum Bulletin 15 and 48th Museum Report, v. 1. 59 x 67 cm. 1894. Scale 14 miles to 1 inch. 15c.
 — Map of the State of New York Showing the Location of Quarries of Stone Used for Building and Road Metal. 1897. *Out of print.*
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 — Geologic Map of New York. 1901. Scale 5 miles to 1 inch. *In atlas form* \$3. *Lower Hudson sheet* 60c.
 The lower Hudson sheet, geologically colored, comprises Rockland, Orange, Dutchess, Putnam, Westchester, New York, Richmond, Kings, Queens and Nassau counties, and parts of Sullivan, Ulster and Suffolk counties; also northeastern New Jersey and part of western Connecticut.
 — Map of New York Showing the Surface Configuration and Water Sheds. 1901. Scale 12 miles to 1 inch. 15c.
 — Map of the State of New York Showing the Location of Its Economic Deposits. 1904. Scale 12 miles to 1 inch. 15c.
 Geologic maps on the United States Geological Survey topographic base. Scale 1 in. = 1 m. Those marked with an asterisk have also been published separately.
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 Area around Lake Placid. 1898.
 Vicinity of Frankfort Hill [parts of Herkimer and Oneida counties]. 1899.
 Rockland county. 1899.
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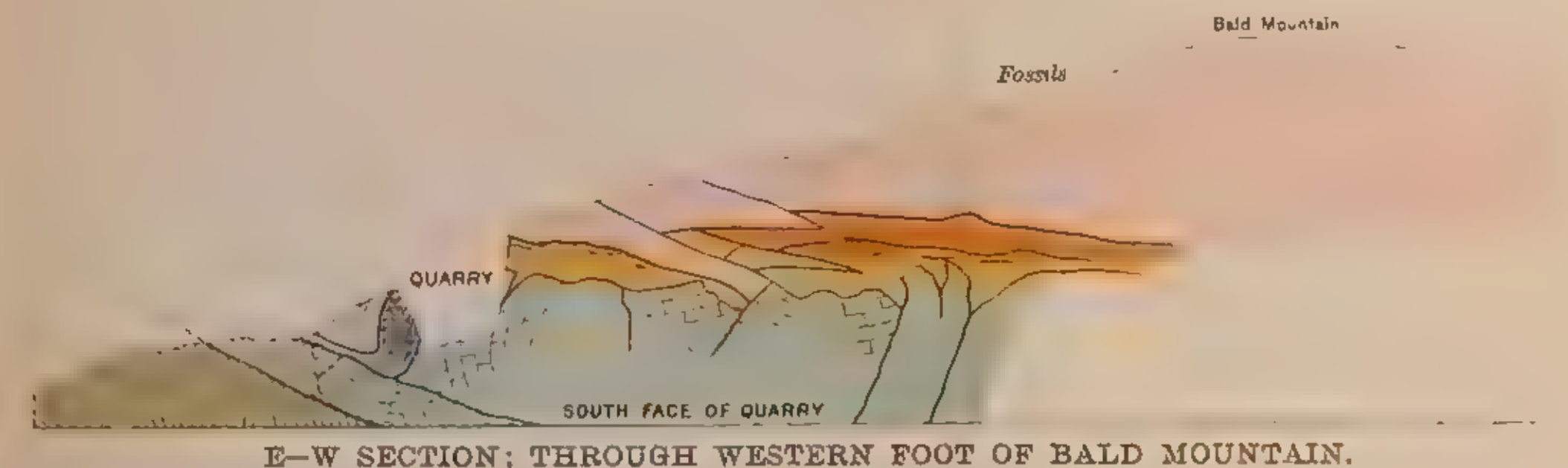
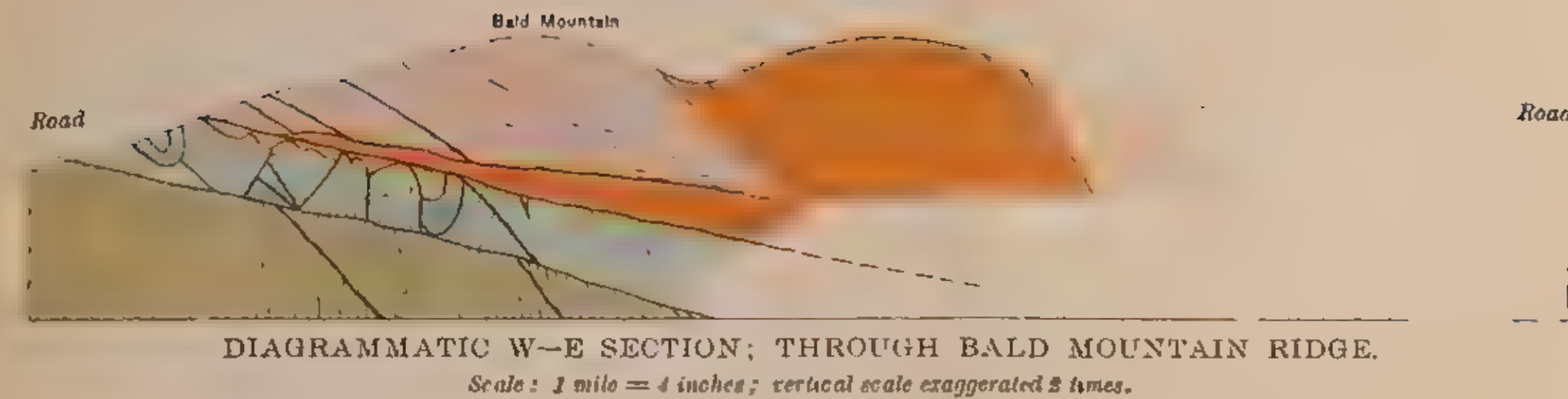
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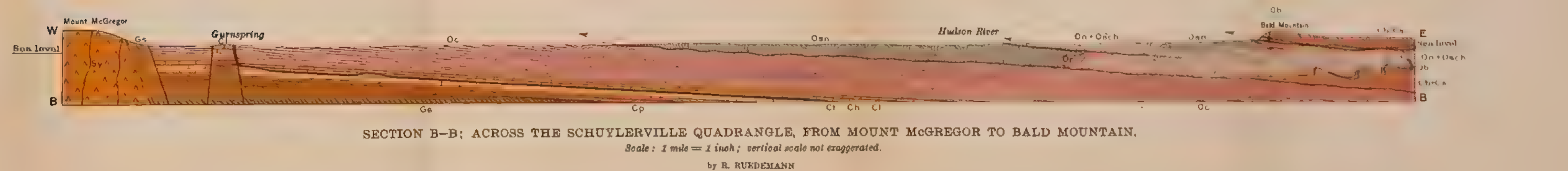
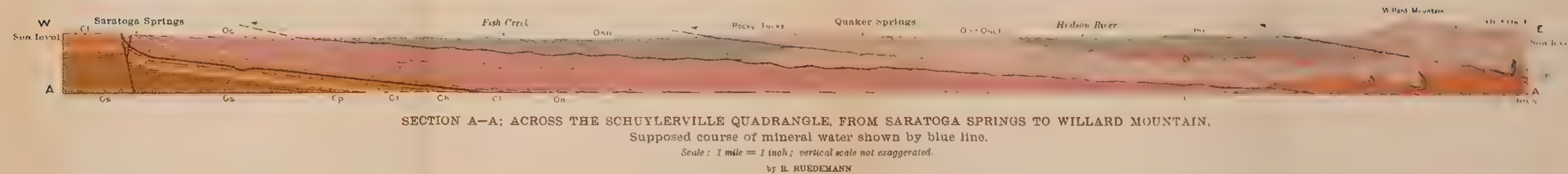
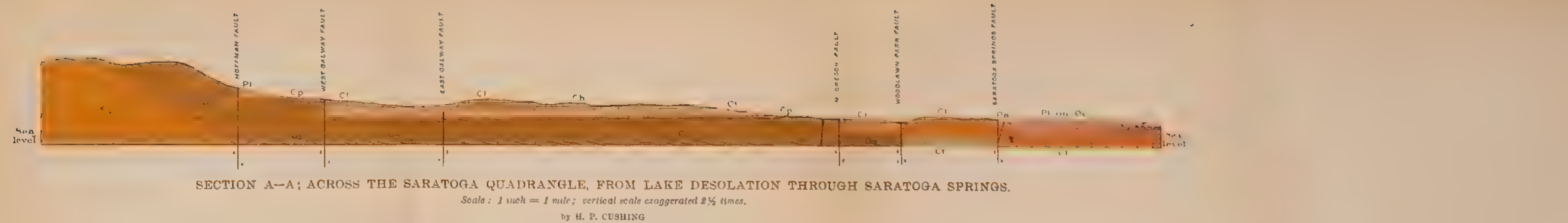


SKETCH OF BALD MOUNTAIN QUARRIES
 a, a. Cliffs of Rysedorph Hill conglomerate left standing.
 b, b. Masses of black shale.
 c, c. Quarry faces (see photos).
 d, d. Exposures of Bald Mountain limestone and dolomite.
 Original surface boundary of Georgian at quarry.



LEGEND

Mylonite.	Rysedorph Hill conglomerate.	Schodack shale and limestone.
Snake Hill shale.	Bald Mountain limestone and dolomite.	Bomoseen grit with quartzite on top.



1. 1. 1.

2. 2. 2.

3. 3. 3.

4. 4. 4.

5. 5. 5.

6. 6. 6.

7. 7. 7.

8. 8. 8.

9. 9. 9.

10. 10. 10.



Geology Schuylerville Quadrangle, by R. Ruedemann and H. P. Cushing, 1910-1912

Geology Saratoga Springs Quadrangle, by H. P. Cushing, R. Ruedemann and W. J. Miller 1908-1910.

Geology Saratoga Springs Quadrangle, by H. P. Cushing, R. Ruedemann and W. J. Miller 1908-1910.

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